Benthic Macrofauna

BIGHT'08

Southern California Bight
2008 Regional Monitoring
Program
Vol. VI

Descriptions and Sources of Photographs on the Cover

Clockwise from top left: **(1)** C. Petry sampling benthic sediment with Van Veen grabs; MBC Applied Environmental Sciences. **(2)** *Amphiodia psara,* H.L. Clark 1935; N. Haring and M. Lilly, City of San Diego Public Utilities Department. **(3)** Bight'08 taxonomist L. Lovell identifying and counting macrobenthic invertebrates; County Sanitation Districts of Los Angeles County. **(4)** The syllid polychaete worm *Odontosyllis* sp. SD2 Velarde 2011 §; Ricardo Martinez Lara, City of San Diego Public Utilities Department. **(5)** The cerithiid gastropod snail *Lirobittium calenum* (Dall 1919); W. Enright, City of San Diego Public Utilities Department.

Southern California Bight 2008 Regional Monitoring Program: VI. Benthic Macrofauna

February 2012

J. Ananda Ranasinghe[1], Kenneth C. Schiff[1], Cheryl A. Brantley[2], Lawrence L. Lovell[2], Donald B. Cadien[2], Tim K. Mikel[3], Ronald G. Velarde[4], Sheila Holt[5], Scott C. Johnson[3]

[1]Southern California Coastal Water Research Project, 3535 Harbor Blvd., Suite 110, Costa Mesa, CA 92626, USA
[2]County Sanitation Districts of Los Angeles County, 24501 S. Figueroa, Carson, CA 90745, USA
[3]Aquatic Bioassay and Consulting Laboratories, Inc., 29 North Olive Street, Ventura, CA 93001, USA
[4]City of San Diego Marine Biology Laboratory, 2392 Kincaid Rd., San Diego, CA 92101, USA
[5]Weston Solutions, Pacific Division, 2433 Impala Dr., Carlsbad, CA 92010, USA

THE BIGHT'08 BENTHIC MACROFAUNA WORKING GROUP

Much of the success of the Southern California Bight Regional Monitoring Program is due to the consensus-based management structure. A Project Steering Committee comprised of environmental managers from each of the participating agencies provides design, oversight, and approval, while the technical work for each discipline is accomplished through Working Groups. The Benthic Macrofauna Working Group was charged with implementing much of the work presented in this report. The members of the Benthic Macrofauna Working Group include:

Member	Affiliation
Jeff Armstrong	Orange County Sanitation District
Chris Beegan	State Water Resources Control Board
Cheryl A. Brantley	County Sanitation Districts of Los Angeles County
Donald B. Cadien	County Sanitation Districts of Los Angeles County
Curtis Cash	City of Los Angeles, Environmental Monitoring Division
David J. Gillett	Southern California Coastal Water Research Project
Nick Haring	City of San Diego, Marine Biology Laboratory
Sheila Holt	Weston Solutions, Inc.
Scott C. Johnson	Aquatic Bioassay and Consulting Laboratories, Inc.
Lawrence L. Lovell	County Sanitation Districts of Los Angeles County
Tim K. Mikel	Aquatic Bioassay and Consulting Laboratories, Inc.
Dean Pasko	Orange County Sanitation District
Tony Phillips	City of Los Angeles, Environmental Monitoring Division
J. Ananda Ranasinghe	Southern California Coastal Water Research Project
Ken Sakamoto	Orange County Sanitation District
Kenneth C. Schiff	Southern California Coastal Water Research Project
Timothy D. Stebbins	City of San Diego, Marine Biology Laboratory
Cristina Thomas	Orange County Sanitation District
Ronald G. Velarde	City of San Diego, Marine Biology Laboratory
David G. Vilas	MBC Applied Environmental Sciences
Shelly Walther	County Sanitation Districts of Los Angeles County
Olga Weaver	Weston Solutions, Inc.

FOREWORD

The Southern California Bight (SCB) is a 100,000-square-mile body of water and submerged continental shelf that extends from Point Conception, California, in the north to Cabo Colnett, Baja California, Mexico in the south. This area is a unique and important ecological and economic resource in southern California that includes diverse habitats for a broad range of marine life including more than 3,000 species of invertebrates, 500 species of fish, and many marine mammals and birds.

The coastal region along the SCB is one of the most densely populated coastlines in the U.S. and the world. The activities of this dense human population stress the coastal marine environment by introducing pollutants from point and non-point sources, modifying natural habitats and increasing fishing pressure.

Over $31 million is spent annually to monitor coastal environmental quality in the SCB. These monitoring programs provide important site-specific information about the impacts of individual waste discharges, but do not assess the condition of the SCB as a whole. The assessment of environmental quality on a more regional scale is needed to help environmental regulators and resource managers understand the consequences of pollution beyond the immediate vicinity of discharge pipes.

The 2008 Southern California Bight Regional Monitoring Program (Bight'08) is an effort to provide an integrated assessment of the SCB through cooperative region-scale monitoring. Bight'08 is a continuation of regional surveys conducted in 1994, 1998, and 2003 that represents the joint effort of more than 90 organizations (Appendix A). Bight'08 is organized into six technical components: (1) Coastal Ecology, (2) Shoreline Microbiology, (3) Water Quality, (4) Areas of Special Biological Significance, (5) Rocky Reefs, and (6) Wetlands. This report presents the results of the benthic macrofauna studies of Bight'08, which is a part of the Coastal Ecology component. Other Coastal Ecology components include sediment toxicity, sediment chemistry, and demersal fish and megabenthic invertebrates. Copies of this and other Bight'08 guidance manuals, data, and reports are available for download at www.sccwrp.org.

The proper citation for this report is: Ranasinghe, J.A., K.C. Schiff, C.A. Brantley, L.L. Lovell, D.B. Cadien, T.K. Mikel, R.G. Velarde, S. Holt, and S.C. Johnson. 2012. Southern California Bight 2008 Regional Monitoring Program: VI. Benthic Macrofauna. Southern California Coastal Water Research Project. Costa Mesa, CA. Technical Report 665.

ACKNOWLEDGEMENTS

This report is the product of the dedication and hard work of many individuals who share a common goal of improving our understanding of the environmental quality of the Southern California Bight. The authors thank all of those who contributed to this report. While space limitations do not allow us to acknowledge all contributors by name, we are grateful to the following people and agencies whose efforts were crucial to our success.

The members of the Bight'08 Steering Committee provided the impetus, vision, and resources that guided and fueled our efforts. The Bight'08 Coastal Ecology Planning Committee coordinated our efforts with other disciplines; their critical and timely reviews improved this document.

The field teams collected our samples with efficiency and care. The captains, crew and scientists on the Avon inflatables (Weston Solutions, Inc. and Aquatic Bioassay and Consulting Laboratories), Early Bird II (Weston Solutions, Inc.), Hey Jude (Aquatic Bioassay and Consulting Laboratories), Kathryn M. (MBC Applied Environmental Sciences), La Mer and Marine Surveyor (City of Los Angeles), Nerissa (Orange County Sanitation District), Ocean Sentinel (County Sanitation Districts of Los Angeles County), Oceanus (City of San Diego), Pon Tiki (MBC Applied Environmental Sciences), Radon (Weston Solutions, Inc.), Shearwater (Channel Islands National Marine Sanctuary), Yellowfin (Aquatic Bioassay and Consulting Laboratories), and Zephr (MBC Applied Environmental Sciences) were responsible for field collection and sample processing. They contributed to our success in no small measure.

The Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) provides a mechanism for standardizing the names of organisms in southern California and promotes communication among taxonomists. They were an integral part of this effort and conducted workshops to prepare taxonomists for organisms in habitats that were sampled in a regional survey for the first time.

We appreciate the efforts and expertise of the taxonomists who produced the primary data on which this report was built. Kelvin Barwick, Cheryl Brantley, John Byrne, Don Cadien, Ross Duggan, Wendy Enright, Bill Furlong, Robin Gartman, Lisa Haney, Nick Haring, Dan Ituarte, Kathy Langan, Megan Lilly, John Ljubenkov, Lawrence Lovell, Chase McDonald, Ricardo Martinez-Lara, Thomas Parker, Dean Pasko, Tony Phillips, William Power, Veronica Rodriguez-Villanueva, James Roney, Timothy Stebbins, and Ron Velarde identified and counted every one of the 179,338 organisms from 1,734 taxa that were collected. Special thanks are due to Cheryl Brantley, who coordinated the data generation process and Lawrence Lovell and the Natural History Museum of Los Angeles County, who coordinated acquisition of the specimens, ensuring their preservation and availability to future generations of scientists.

Specialty taxonomists identified and counted groups of animals that were previously not consistently and reliably identified bight-wide, and prepared documentation and training materials to improve the state of the science. John Ljubenkov was specialty taxonomist for Cnidaria, Tony Phillips for Enopla Nemertea, and Ronald G. Velarde for Syllidae Polychaeta.

The Benthic Macrofauna Working Group Committee worked cooperatively on all aspects of data collection, sample processing, data analysis, and report preparation. Discussions were open and thoughtful, and the synergy of different perspectives resulted in new and productive ideas.

We are grateful to Kerry Ritter and Becky Schaffner for implementing the sampling design, Becky Schaffner for making the maps, Bruce Bealer for maintaining the database and internet data submission system, Cheryl Brantley for coordinating acquisition of the cover photographs and arranging their layout and Valerie Raco-Rands for layout of the cover. The efforts of these individuals made many complicated tasks seem easy.

Participating Benthic Laboratories

Aquatic Bioassay and Consulting Laboratories, Inc.
City of Los Angeles, Environmental Monitoring Division
City of San Diego, Marine Biology Laboratory
MBC Applied Environmental Sciences
Orange County Sanitation District
County Sanitation Districts of Los Angeles County
Weston Solutions, Inc.

EXECUTIVE SUMMARY

Organisms that live in sediments beneath bodies of water (benthic organisms) have many characteristics that make them useful as indicators of environmental stress for monitoring programs. Benthic organisms have limited mobility, respond to many different stressors, and integrate the effects of environmental conditions over time. Benthic organisms are also relevant measures of environmental condition because they represent the biological resources that are the focus of many environmental laws and regulations. This report describes the benthic macrofaunal studies of the Southern California Bight (SCB) Regional Marine Monitoring Program (Bight'08), the fourth SCB regional survey. The objectives of the report are to estimate the extent and magnitude of altered benthic macrofaunal communities in the SCB, and to evaluate whether the extent and magnitude of altered communities vary among habitats of interest. Additionally, the three previous surveys between 1994 and 2008 were used to evaluate temporal changes in benthic infaunal status.

Benthic macrofauna were successfully collected and processed from 382 sites between Point Conception, California, and the United States-Mexican border using a random tessellation stratified (RTS) study design. Sites ranging in depth from 0.3-1023 m were stratified into 10 habitats including: inner (5 - 30 m), middle (31 - 120 m), and outer (121 - 200 m) continental shelf; Channel Island continental shelf (5 - 200 m); upper continental slope (201-500 m); lower continental slope and basins (501 - 1,000 m); estuaries, ports, marinas, and other bays. At each site, samples were collected with a 0.1-m^2 Van Veen grab, sieved through a 1-mm mesh screen, placed in a relaxant solution for at least 30 minutes and fixed in buffered 10% formalin. In the laboratory, samples were sorted into major animal groups and the specimens in each group were identified to the lowest practical taxon, most often species, and counted.

Extensive quality assurance and quality control measures were implemented and no data were excluded from the study due to lack of appropriate quality. All participating vessels and field crews passed audits to ensure capability and comparability. All laboratory identification data quality objectives were met. The mean sorting efficiency was 93.9% and identification quality control reanalysis of 10% of the samples identified mean error rates of 2.5, 5.0, and 6.4% in abundance, number of taxa, and identification accuracy, respectively. These results meet or surpass the performance of any other national benthic program that quantifies data quality. This high level of quality assurance is due, in part, to activities of the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) who focus on resolving problems associated with sample processing, taxonomic standardization, and specialist identification of especially difficult taxa.

Two assessment tools were used to achieve the benthic regional monitoring program objective of assessing the extent and magnitude of altered benthic communities. The first was the Benthic Response Index (BRI) that was developed in 1994 (Smith *et al.* 2001). The BRI is a multivariate measure that is used to assess the mainland and island shelf from 10 to 200 m. The second assessment tool was the Sediment Quality Objectives Benthic Line of Evidence (BLOE), which was developed for marine bays and estuaries as part of Bight'03. The BLOE is a combination of multivariate and multi-metric biointegrity indices. Both indices were developed and validated to yield a result on the same four-category condition scale from undisturbed to

highly disturbed (Reference to Response Level 3). Response Levels 2 and 3 (moderate disturbance and high disturbance) are clear evidence of disturbed benthic communities, while Reference and Response Level 1 (low disturbance) represent unaltered benthic communities.

Overall, the SCB benthos were in good condition during 2008. Benthic macrofauna in 99.7% of the SCB were in reference condition or deviated only marginally from reference. There was no evidence of disturbance on the island shelf or the mainland shelf. Macrofaunal communities in embayments, on the other hand, were more frequently disturbed. Slightly over 12% of the area in these embayments contained clearly disturbed benthos, with the greatest frequency occurring in estuaries and marinas. Benthic communities in poor condition occupied more than half the area (59.0%) of southern California estuaries and more than a third of the area (37.4%) in marinas. No assessment was made for some habitats of interest, including slopes and basins (>200 m), the shallowest areas (<10 m deep) of the inner shelf, and brackish water embayments with salinity <27 psu, because assessment tools currently do not exist for these habitats.

Regional benthic community condition has not changed dramatically between 1994 and 2008. No significant differences were observed in the areal extent of disturbed benthos in habitats that were sampled in more than one regional survey. The areal extent of disturbed benthic community has remained less than 4% of the SCB for the last 15 years. Similarly, there was no consistent pattern of change at sites that were sampled in more than one regional monitoring survey. Trend information for other habitats, such as estuaries and the upper slope, which were only sampled in 2003 and 2008, cannot be assessed yet.

In order to improve cost-efficiency in sampling and laboratory identification for embayment sites, a special study was conducted to assess differences in biological community composition and benthic condition estimates based solely on differences in sampled surface area. Ultimately, none of the tested sample areas were clearly preferable to the existing standard method of 0.1 m^2. For example, the cost for laboratory taxonomic analysis decreased by a factor of five using a sampled surface area of 0.01 m^2, but the estimated area of embayments with disrupted benthic condition increased from 12% to over 50% when based on the smaller sampled area, an unacceptable overestimate.

Future regional surveys are urged to: 1) calibrate and validate new assessment tools for habitats of concern; 2) improve cost-effectiveness in sampling embayments and subsequent taxonomic identification; 3) maintain taxonomic continuity to assure accuracy and reliability; 4) improve our understanding of the mechanism(s) of impact in estuaries; and 5) implement procedural recommendations to increase efficiency and ensure timely completion of the project.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

Benthic macrofauna are useful indicators of the condition of marine (Pearson and Rosenberg 1978, Smith *et al.* 2001, Borja *et al.* 2003, Ranasinghe *et al.* 2003a, Rosenberg *et al.* 2004) and estuarine (Tapp *et al.* 1993, Engle *et al.* 1994, Wilson and Jeffrey 1994, Alden *et al.* 1997, Dauer 1997, Engle and Summers 1999, Van Dolah *et al.* 1999, Paul *et al.* 2001, Llansó *et al.* 2002, Thompson and Lowe 2004) environments. Benthic macrofauna include a diverse mixture of species with a wide range of physiological tolerances. They are also well-suited for use as indicators because they respond to many different types of environmental stress. Their responses also integrate environmental conditions over time because benthic macrofauna have limited mobility and cannot avoid adverse conditions.

Most benthic macrofaunal monitoring in the Southern California Bight (SCB) has been used to evaluate the effect of discharges from individual sources, such as municipal wastewater outfalls (Stull *et al.* 1986, Zmarzly *et al.* 1994, Diener *et al.* 1995, Dorsey *et al.* 1995, City of San Diego 2006, Los Angeles County Sanitation Districts 2006, Orange County Sanitation District 2006), thermal and industrial outfalls (Barnett *et al.* 1987, Southern California Edison Company 1997), disposal of dredged material and drilling mud (U.S. Environmental Protection Agency 1987), and stormwater runoff (Bay and Schiff 1997, MEC Analytical Systems Inc and Weston Solutions Inc. 2005, Weston Solutions Inc 2005). These studies are site-specific, focusing largely on the discharge of interest, and cannot be generalized to a regional scale.

Regional surveys enable larger spatial scale evaluations of biological condition. For example, the University of Southern California conducted regional studies between 1956 and 1959 (Allan Hancock Foundation 1959, Barnard and Hartman 1959, Barnard and Ziesenhenne 1960, Stevenson 1961, Allan Hancock Foundation 1965, Jones 1969). These data helped describe the previously unknown biological and geophysical characteristics of the SCB. The Southern California Coastal Water Research Project (SCCWRP) conducted regional surveys in 1977, 1985, and 1990 (Word and Mearns 1979, Thompson *et al.* 1987, Thompson *et al.* 1993b), providing valuable descriptions of regional reference biological and physical-chemical conditions.

The benthic macrofaunal component of regional monitoring surveys after 1990 has matured greatly compared to the early regional surveys prior to 1990 (Setty *et al.* 2010). Three regional monitoring surveys have been conducted including one in 1994 (Bergen *et al.* 1998, 2000), 1998 (Ranasinghe *et al.* 2003a), and 2003 (Ranasinghe *et al.* 2007, Ranasinghe *et al.* 2010). Post-1990 regional surveys are designed not only for biological characterization and to quantify regional reference condition, but also to assess the spatial extent and magnitude of impact to benthic macrofauna. These new designs provide an opportunity to evaluate cumulative effects from multiple point source and non-point source discharges. In addition, the new regional monitoring surveys have improved benthic macrofaunal condition assessments by aiding taxonomic standardization (Ranasinghe *et al.* 2003b, Southern California Association of Marine Invertebrate Taxonomists 2008), developing assessment tools (Smith *et al.* 2001, Ranasinghe *et al.* 2009), and evaluating new habitats (Ranasinghe *et al.* 2007, Ranasinghe *et al.* 2010). Ultimately, these regional survey data were used by the State Water Resources Control

Board to help develop Sediment Quality Objectives for California's bays and estuaries (Bay and Weisberg 2008, Ranasinghe *et al.* 2009, Bay and Weisberg In Press).

This report describes the benthic macrofaunal studies of the Southern California Bight Regional Marine Monitoring Program (Bight'08), the fourth SCB regional survey. The objectives of the report are to estimate the extent and magnitude of altered benthic macrofaunal communities in the SCB, and to evaluate whether the extent and magnitude of altered communities vary among geographic regions (Bight'08 Coastal Ecology Committee 2008). Additionally, the three previous surveys between 1994 and 2008 were used to evaluate temporal changes in benthic infaunal status.

The report is organized into nine chapters and five appendices. The chapters address the objectives of the report and ancillary studies, while the appendices provide additional detail.

Chapter II describes the study design and the field, laboratory, and data analysis methods. Chapter III presents the quality assurance procedures that ensured comparability of data produced by participating organizations and the results of quality control audits measuring their success. Chapters IV, V and VI present our descriptive results, assessment results, and an ancillary study evaluating the effect of gear area on embayment sample assessments. The results are discussed in Chapter VII. Chapters VIII and IX present our conclusions and recommendations. Chapter X lists the literature cited in the other chapters.

Appendix A presents a list of organizations participating in Bight’08. Appendices B thru G contain detailed data and results supplementing Chapters IV and V. Appendix B presents sampling stratum community measure means, minimums, and maximums while Appendix C presents taxonomic composition for the sampling strata. Appendix D contains detailed maps presenting assessments of benthic condition at our sampling sites. Appendices E and F present values for several community measures at Bight’08 coastal and embayment sampling sites, respectively. Appendix G is a list of benthic taxa collected in Bight’08.

II. METHODS

This section describes the study design and the field, laboratory, and data analysis methods used to generate benthic data and estimate the extent and magnitude of altered benthic communities in the Southern California Bight (SCB) and selected geographic areas.

Study Design

Benthic samples were collected at 382 sites in the SCB between Point Conception, California and the United States-Mexican border. Sites were selected at random using a random tessellation stratified (RTS) design and the sampling results were used to assess the condition of the SCB. RTS designs are similar to stratified random designs, but samples are distributed more evenly across strata by subdividing the area into hexagons and collecting a sample at a random location in each hexagon (Bergen 1996, Stevens 1997). Imposition of the hexagonal pattern minimizes clustering of the random samples. At least 30 samples were allocated to each stratum to provide adequate statistical power for data analysis.

Table II-1. Bight'08 random tessellation stratified samples. Shown are strata (geographic areas of interest), their area in km^2 and as a percentage of the total area, and the numbers of samples that were collected.

Habitat	Stratum (Depth range)	Area (km^2)	%	Samples
Estuaries	Estuaries	11.9	0.1	64
Bays	Marinas	17.5	0.1	44
	Ports	29.3	0.2	46
	Bays	70.0	0.4	38
Mainland Shelf	Inner Shelf (5-30 m)	1,171	7.0	30
	Mid Shelf (31-120 m)	2,019	12.0	30
	Outer Shelf (121-200 m)	605	3.6	30
Island Shelf	Channel Island Shelf (5-200 m)	2,193	13.1	30
Slopes and Basins	Upper Slope (201-500 m)	3,130	18.7	35
	Lower Slope & Basins (501-1000 m)	7,535	44.9	35
Total		**16,782**	**100.0**	**382**

To facilitate detection of temporal trends, 129 station locations sampled in previous regional monitoring surveys were sampled again during Bight'08. Details are presented in Table II-2.

Field Methods

Sediment samples for benthic macrofauna analysis were collected from July 2nd to September 29th 2008 with a 0.1 m^2 Van Veen grab and sieved through a 1 mm mesh screen. Only samples penetrating at least 5 cm into the sediment with no evidence of sediment disturbance (e.g., washout or slumping) were processed. Material retained on the screen was placed for at least 30 minutes in a relaxant solution of 1 kg $MgSO_4$ or 30 ml propylene phenoxytol per 20 L of seawater, and then preserved in 10% sodium borate buffered formalin. Additional sediment samples were collected for analysis of sediment contaminants and sediment toxicity; these results are provided elsewhere (Bay *et al.* 2011, Schiff *et al.* 2011).

Table II-2. Numbers of stations sampled in previous regional surveys that were revisited in 2008

Stratum	Previously sampled in		Total
	1998	2003	
Estuaries		17	17
Marinas	10	10	20
Ports	10	6	16
Bays	7	10	17
Inner Shelf	6	8	14
Mid Shelf	7	8	15
Outer Shelf		15	15
Channel Island Shelf	7	8	15
Total	**47**	**82**	**129**

Laboratory Methods

Samples collected for macrofaunal analysis were distributed to five laboratories for sorting, identification, and enumeration. Samples were rinsed and transferred from formalin to 70% ethanol 3-14 days after collection. Organisms in the samples were sorted into taxonomic categories and distributed to experienced taxonomists for species identification and enumeration.

Data Analysis

The primary objective of this report was to assess the extent of SCB area with altered benthic assemblages. “Altered benthic assemblages” differ from expectations for reference assemblages by exhibiting some indication of disturbance, which in turn connotes stress. It is generally recognized that current models of benthic response do not discriminate between anthropogenic and natural sources of disturbance (Borja *et al.* 2003).

The extent of area with benthic assemblages showing clear evidence of disturbance was estimated in two steps. The condition of the benthic assemblage at each site was first assessed using a measure of biointegrity. Then individual site assessments were combined to assess the extent and magnitude of alteration in geographic areas of interest (strata).

Benthic condition at each site was assessed on a four-category scale (Table II-3):

- Reference communities are expected to occur at undisturbed sites.
- At Response Level 1 (low disturbance), communities exhibit some indication of stress, but only within the measurement variability of reference condition.
- At Response Level 2 (moderate disturbance), communities exhibit clear evidence of physical, chemical, other anthropogenic, or natural stress.
- At Response Level 3 (high disturbance), communities exhibit a high magnitude of stress.

Response Levels 2 and 3 are considered to be clear evidence of disturbed benthic communities (“poor condition”) while Reference and Response Level 1 are not.

Two different measures of biointegrity were used to assess coastal sites and sites in embayments because of ecological and benthic species composition differences. Coastal sites were assessed with the Benthic Response Index (BRI; Smith *et al.* 2001). The same index was used to assess coastal sites for the 1994, 1998 and 2003 regional surveys. The response categories used here correspond to Smith *et al.* (2001) Response Levels, except that the original Response Levels 3 and 4 were combined into Response Level 3 for this assessment.

Table II-3. Characterization of response categories in coastal and embayment habitats. Coastal sites were evaluated using the BRI (Smith *et al.* 2001). Embayment sites were evaluated using the SQO Benthic Line of Evidence (Ranasinghe *et al.* 2009).

Benthic Response Level	Benthic Condition	Coastal Sites	Embayment Sites
Reference	Good	Reference	Reference
Level 1		Marginal deviation	Low Disturbance
Level 2	Poor	Biodiversity loss	Moderate Disturbance
Level 3		Community function loss or defaunation	High Disturbance

In embayments, the SQO Benthic Line of Evidence (BLOE), which is functionally equivalent to the coastal BRI, was used to assess benthic condition at each site. The BLOE is a combination of four benthic indices that performed better than any of the individual indices during bay assessment tool development (Ranasinghe *et al.* 2009). The BLOE combines the BRI, Relative Benthic Index (RBI), Index of Biotic Integrity (IBI), and a predictive modeling method based on the River Invertebrate Prediction and Classification System (RIVPACS). Each index was developed and validated to yield a result on the same four-category response level scale. The results were combined by expressing the categories numerically, with Reference = 1, Response Level 1 = 2, Response Level 2 = 3, and Response Level 3 = 4 and calculating the median of the four index results. If the median yields a decimal result it is rounded up to the next integer (in a conservative or protective direction). More details about these index approaches and their calibration to southern California bay data are provided by Ranasinghe *et al.* (2009).

Table II-4 presents the areas that were assessed for Bight'08 and the numbers of assessment samples collected in 2008. It also includes the numbers of samples collected from equivalent geographic areas and habitats for three previous surveys in 1994, 1998, and 2003 that were used for multiple survey comparisons. Although geographic area definitions were not identical for all three surveys, they were similar and comparable. Bight'08 stratum geographic and depth definitions and limits were applied to samples from all surveys to ensure consistency of comparisons. Due to limitations of the biointegrity measures, it was not possible to assess every sample that was collected. For example, slope and basin samples from strata deeper than 200 m were not assessed because of concerns about potential inaccuracies of the BRI biointegrity measure near the limits of its applicable depth range. Although the BRI was calibrated in 1994 with samples up to 324 m deep, subsequent applications indicated bias toward the extremes of its depth range and substantial changes in species composition and abundance were observed at depths of about 200 m that potentially contribute to the bias. Because of these changes, and because most of the data used to calibrate the BRI were collected at depths <200m, we chose to limit its application to this depth. Embayment samples where bottom water salinity was less than 27 psu were not assessed because the SQO BLOE was not developed for oligohaline (0.5 to 5 psu), mesohaline (5 to 18 psu), or polyhaline (18-27 psu) salinities. The shallowest areas (< 10 m deep) of the inner shelf were not assessed because the BRI (Smith *et al.* 2001) is not applicable there.

Table II-4. Spatially random samples used for assessment and temporal comparisons. Shown are designated geographic areas of interest (strata), their area, and the numbers of samples for which benthic assessment data were available. The strata presented follow Bight'08 stratum geographic and depth definitions. Strata were similar, but not identical, between surveys because the sampling design was altered to emphasize different areas.

Habitat	Stratum	Area Assessed (km^2)	Samples			
			1994	1998	2003	2008
Embayments	Estuaries	11.9			39	58
	Marinas	17.5		40	32	44
	Ports	29.3		39	9	46
	Bays	70.0		34	18	38
Coast	Inner Shelf (5-30m)	1,171	69	60	43	30
	Middle Shelf (31-120m)	2,019	138	81	72	32
	Outer Shelf (121-200m)	605	38		25	28
	Channel Island Shelf (5-200m)	2,193		36	32	30
Total		6,117	245	290	270	306

Our estimates of benthic condition were based on benthic community condition categories at our sampling sites. By virtue of the RTS sampling design, each sample represents a known area, which is called the sample area weight. To obtain the total area at a condition category, all the area weights for samples at that condition category were summed. The proportion of area at a response level is the response level area divided by the total area. Sample area weights may not be equal throughout a stratum because additional samples may be allocated to facilitate evaluation of small, but important, areas.

For statistical analysis, the four-category results were transformed to binary values by coding Reference and Response Level 1 samples as 0 ("Good Condition"; Table II-3) and Response Level 2 and 3 samples as 1 ("Poor Condition"). The proportion of area exceeding the good-poor threshold was then calculated as the mean of the scores using Thompson's (1992) ratio estimator:

$$m = \sum_{i=1}^{n} (p_i * w_i) \Big/ \sum_{i=1}^{n} w_i$$

where m is the mean score, p_i is the score at station i, w_i is the area weight for station i, and n is the number of stations sampled. The ratio estimator was used instead of a stratified mean because an unknown fraction of each stratum cannot be sampled (e.g., hard bottom). The estimated area, a random variable, was used as a divisor in place of the unknown true area that can be sampled. The standard error of the mean response was calculated as:

$$s = \sqrt{\sum_{i=1}^{n} ((p_i - m) * w_i)^2 \Big/ (\sum_{i=1}^{n} w_i)^2}$$

The 95% confidence intervals were calculated as 1.96 times the standard error. Use of the ratio estimator for the standard error approximates joint inclusion probabilities among samples and assumes negligible spatial covariance, an assumption that, based on the data, appears to be warranted. The assumption is conservative since violation would lead to an overestimate of the confidence interval (Stevens and Kincaid 1997).

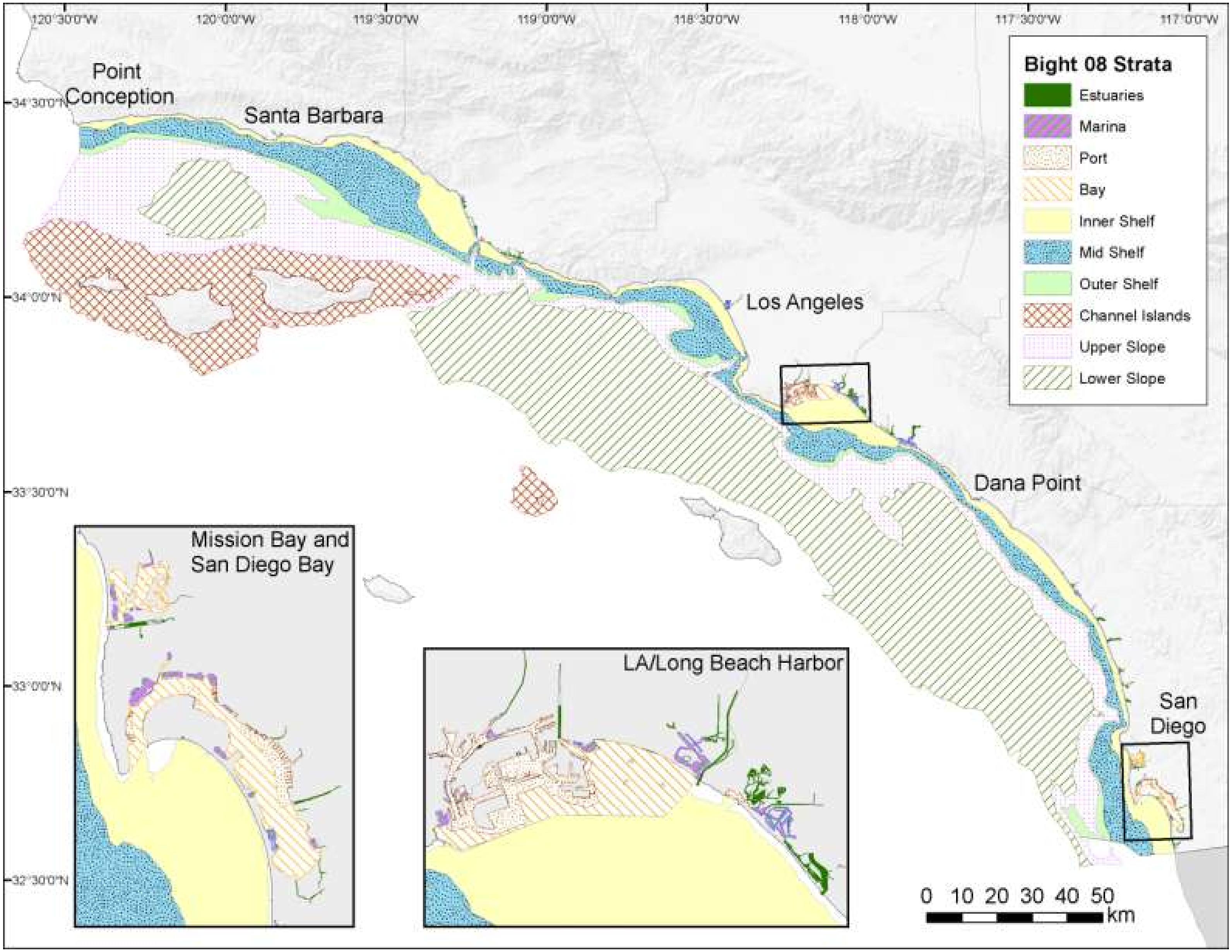


Figure II-1. Geographic areas of interest (strata) for Bight'08. Benthic condition was not assessed for bottoms deeper than 200m (the upper and lower slopes and basins) due to lack of a validated benthic assessment tool.

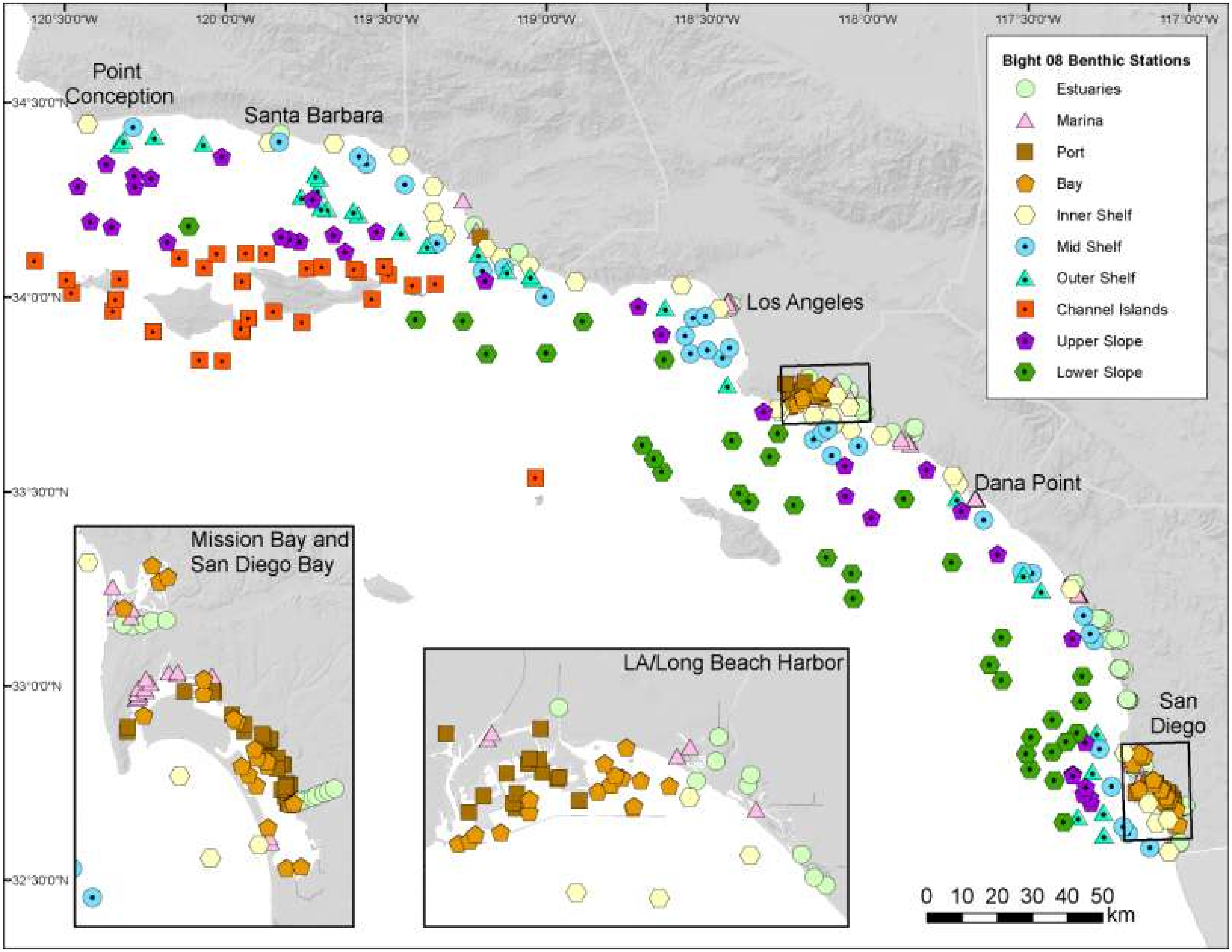


Figure II-2. Locations of random tessellation stratified (RTS) sampling sites for Bight'08.

III. QUALITY ASSURANCE AND QUALITY CONTROL

Benthic macrofaunal community composition was included in the Bight'08 Coastal Ecology Work Plan (Bight'08 Coastal Ecology Committee 2008) as an indicator of biotic responses in sediments. Measuring community composition entails accurately collecting, identifying, and counting the organisms that are captured in samples. This chapter describes the field and laboratory procedures that ensured the quality of these data and presents the results of quality control audits, inter-team comparisons, and other statistics that document this process. The overall approach was to establish data quality objectives and assessment standards; produce manuals specifying field, laboratory, and data submission procedures; evaluate procedural compliance using field and laboratory audits; and evaluate achievement of those objectives and standards using inter-team comparisons and other measures.

Data Objectives

The overall goal of the macrofaunal survey was to provide accurate identifications and abundance counts of all of the benthic invertebrates within 18 months of sample collection. The identifications were to be as precise as practicable (i.e., to the lowest taxonomic category) with a goal of species-level identification for all specimens whose condition allowed it. The level of precision was driven by the analytical uses of the data, which included description of assemblages, and the development and application of assessment indices that depend on the distributions of species along disturbance gradients.

To achieve this goal, measurement quality objectives (MQOs) were specified for several measurements and processes (Table III-1) in the Work Plan (Bight'08 Coastal Ecology Committee 2008). An MQO specifies the acceptable level of uncertainty for each measurement or process and is based on assessment standards developed in the Bight'08 Coastal Ecology Work Plan.

Table III-1. Measurement quality objectives for benthic macrofaunal sample collection and processing. NA: not applicable.

Activity	Accuracy	Completeness
Sample collection	NA	90% of work plan target number of stations
Station occupation	Within 100m*	NA
Sorting	95%	95%
Total abundance	90%	90%
Number of taxa	90%	90%
Identification	90%	90%

* Within 200m for Channel Island Shelf sites

Field and Laboratory Manuals

As part of the planning effort, manuals were developed that specified procedures for field sampling (Bight'08 Field Sampling & Logistics Committee 2008) and laboratory activities affecting benthic invertebrate samples (Bight'08 Benthic Committee 2008). These manuals were designed to produce consistency in the collection, handling, and processing of samples in order to meet Bight'08 survey goals, MQOs, and sample processing timelines.

An Information Management Plan (Bight'08 Information Management Committee 2008) imposed data reporting standards and data screening procedures to ensure that inconsistencies were not introduced as a result of differences in the manner in which species data were reported. The plan included formats and specifications for data submissions as referenced in the laboratory manual. This plan also included provisions for electronic submission of species data with automated error checking and reporting routines

Sample Collection

Prior to sampling, participating vessels were inspected and field crews audited to ensure that they were properly equipped and trained. Experienced biologists familiar with the sampling techniques conducted the audits. All vessels and field crews successfully passed the audits.

A total of 382 benthic macrofaunal grab samples were collected from ten random tessellation stratified assessment strata. The overall rate of successful sample collection (i.e., a station was occupied and grab samples successfully collected) was 93.6 % (Table III-2), achieving the MQO. As was the case in Bight'98 and Bight'03, the island shelf was the most difficult habitat in which to collect grab samples, with only 81% of the attempts to occupy a site resulting in success. The most frequent cause of sampling failure in coastal habitats was the presence of rocky bottom, more prevalent on insular shelves than other sampled habitats (Table III-3). In embayment habitats, the most frequent cause of sampling failure was the lack of access to Port sampling sites due to military reservations (Table III-3).

Table III-2. Sample collection success.

Habitat	Stratum	Sampling Sites			Stratum Completeness (%; MQO=90)
		Attempted	Collected	Success (%)	
Estuaries	Estuaries	67	64	95.5	106.7
Bays	Marinas	45	44	97.8	146.7
	Ports	54	46	85.2	153.3
	Bays	38	38	100.0	126.7
Mainland Shelf	Inner Shelf	31	30	96.8	100.0
	Mid Shelf	30	30	100.0	100.0
	Outer Shelf	30	30	100.0	100.0
Island Shelf	Channel Island Shelf	37	30	81.1	100.0
Slopes & Basins	Upper Slope	36	35	97.2	116.7
	Lower Slope & Basins	40	35	87.5	116.7
Total		**408**	**382**	**93.6**	**115.8**

The Coastal Ecology sampling objective was to collect 30 samples within each random tessellation stratified assessment stratum, except estuaries, where the objective was 60 samples. The stratum sampling completeness MQO was 90% of the Coastal Ecology sampling objective, which was exceeded in all the strata (Table III-2). For most strata, the goal was to allocate approximately 30 sites to each stratum because this yields an area extent estimate with a precision of about ±10% for the 90% confidence interval (assuming a binomial probability distribution and p=0.2). Estuarine habitats are more variable than other habitats and, therefore, estuarine sampling intensity was doubled in an attempt to adequately characterize the increased variability.

Table III-3. Reasons for abandonment.

Reason	Abandonments
No access (Military reservation)	9
Grab failure – hard bottom	9
No contact with bottom (too deep)	3
Low salinity (<19 psu)	2
No access (Marina)	1
Kelp bed	1
On land	1
Total	**26**

Station Occupation

The MQO for station occupation accuracy (200 m for Channel Island shelf stations, 100 m for all others) was achieved for 99% of the stations (Table III-4). Only one island shelf station and three other stations failed to meet the MQO. The notable improvement in occupation accuracy over previous surveys reflects improved navigation equipment, and improved automated record keeping by the Bight'08 Field Data System. Manual data entry in previous surveys was a significant source of positional data entry errors.

Table III-4. Station occupation accuracy.

Habitat	Stratum	Sites	Distance from nominal location (m)*							
			<5	5-10	10-25	25-50	50-75	75-100	100-200	>200
Estuaries	Estuaries	64	15	15	14	9	6	5		
Bays	Marinas	44	5	4	7	19	8	1		
	Ports	46	1	4	17	15	5	3	1	
	Bays	38	1		13	15	6	3		
Mainland Shelf	Inner Shelf	30		5	10	8	5	1	1	
	Mid Shelf	30	1	3	11	8	6	1		
	Outer Shelf	30		5	7	12	2	3	1	
Island Shelf	Channel Island Shelf	30	1		6	7	7	5	4	
Slopes & Basins	Upper Slope	35		2	12	7	10	3		1
	Lower Slope & Basins	35	1	4	9	11	4	6		
	Total	**382**	**25**	**42**	**106**	**111**	**59**	**31**	**7**	**1**
	%		**6.5**	**11.0**	**27.7**	**29.1**	**15.4**	**8.1**	**1.8**	**0.3**

*: Distance from benthic grab to nominal location, in meters

Other Field Operational Guidelines

The Bight'08 Field Operations Manual required field crews to comply with several other operational guidelines to assure that the benthic samples were of consistent and high quality. All samples were to be collected during the index period of July 1 through September 30, 2008. In 2003, the difficulty of sampling within estuaries required that additional random sites be drawn at the end of the index period in order to collect a sufficient number of samples and the last sample was collected approximately two weeks after the designated index period closed. In 2008, the early designation of an adequate number of overdraw stations to be sampled in case of sampling failure facilitated collection of all samples during the index period. All samples were to be collected between sunrise and sunset and only one sample failed to meet this requirement. All samples met the grab acceptability requirements of minimum penetration (>5cm) and no surface sediment disturbance. Coastal strata were defined using depth criteria and sampling sites were selected using Geographic Information Systems (GIS) and bathymetric maps. Due to inaccuracy of the bathymetric maps, three samples failed to meet the depth criteria (Table III-5) and were moved to the appropriate strata. The overall effect on survey design was negligible.

Table III-5. Stratum depth criteria compliance at coastal sites.

Habitat	Stratum	Criterion (m)	Samples		Performance (%)
			Attempted	Met criterion	
Mainland Shelf	Shallow	5-30	30	30	100.0
	Mid	30-120	30	30	100.0
	Deep	120-200	30	28	93.3
Island Shelf	Island Shelf	5-200	30	30	100.0
Slopes & Basins	Upper Slope	200-500	35	34	97.1
	Lower slope & Basins	500-1000	35	35	100.0

Fifteen research vessels and sampling teams collected benthic samples during Bight'08. Each crew was responsible for submitting all field records related to the collection of benthic grabs within three months of the close of the index period. These records include two data types: station occupation and grab event data.

Sorting

Five laboratories sorted the 382 samples and conducted resorts and other sorting quality control (QC) measures as specified in the laboratory manual (Table III-6). Achievement of the MQO of ≥ 95% sorting efficiency (i.e., removal of at least 95% of the specimens for identification and enumeration) was verified using one or more of several QC methods. The minimum requirement was a 10% aliquot recheck of each sample, or a 100% recheck of 10% of total samples. No laboratory chose the second method. Several laboratories chose QC methods that went beyond the minimum requirement (column three of Table III-6) by increasing the recheck aliquot percentages (20% - Lab B and 50% - Lab E) or performing 100% rechecks on a subset of samples (Labs A and B). Laboratory D performed 100% QC rechecks on all their samples.

The initial sorting efficiency of the laboratories ranged from 99.5% - 84.4 % with a mean of 93.9% (Table III-6). These results required complete re-sort of 101 samples (26.4% of total) to ensure that the MQO was exceeded. Fifty-five of the 382 Bight '08 samples (14.4%) had abundances ≤ 50 individuals. In low abundance samples, three or more animals found during a sort QC review would yield <95% sorting efficiency and, therefore, a re-sort was required. After application of the quality control measures, all samples met or exceeded the sorting MQO of 95%.

Sorters at some laboratories were less experienced also resulting in more re-sorts. Sorting is a technical skill that requires many, many hours to become highly efficient. Sample processing techniques can increase the likelihood of capturing animals, but recognition of some animals and sediment tubes that might contain animals is only acquired with experience.

Table III-6. Sorting Efficiency (MQO ≥ 95%) and Sorting Quality Control (QC) Methods

Lab	# Samples	Method(s)	Efficiency %	# Re-sorts*
A	162	1,4	95.1	48
B	83	2,5	99.5	1
C	46	1	93.3	15
D	49	4	97.4	7
E	42	3	84.4	30
Totals	**382**		**93.9**	**101 (26.4%)**

Sorting QC Methods:
1 – 10% aliquot recheck
2 – 20% aliquot recheck
3 – 50% aliquot recheck
4 – 100% recheck of sample
5 – 100% recheck of 10 samples by Lab B as QC of contract lab effort
Minimum requirement:10% recheck of each sample (Method 1) or 100% recheck of 10% of samples (not utilized)
Methods 2-5 exceed the minimum sorting QC requirement

Identification and Enumeration

The goal of the macrofaunal survey was, as in previous Bight surveys, to identify all benthic invertebrates contained in the samples to species level and count them. The precision of identification increased slightly over previous surveys, with 83.3% of the collected organisms identified to species in Bight'08 (Table III-7), 75.6% in Bight'03 and 82.0% in Bight'98. The percentage of names at the species level was similar in all three surveys. Of the 1,734 taxa reported in Bight'08, 75.7% were at the species level; in Bight'03 and Bight'98, 76.3% and 76.5% of 1,664 and 1,415 taxa, respectively, were at the species level.

Table III-7. Success at species-level identification. Of 1,734 taxa reported, 1,313 (75.7%) were at the species level.

Habitat	Number of Organisms	Species-level Identification	
		N	%
Estuaries	49,387	40,040	81.1
Bays	78,105	65,642	84.0
Mainland Shelf	28,672	24,383	85.0
Channel Island Shelf	19,492	16,214	83.2
Upper Slope	2,395	2,061	86.1
Lower Slope & Basins	1,287	990	76.9
Total	**179,338**	**149,330**	**83.3**

Species-level identification success was achieved despite an increased number of estuarine samples and additional complexity due to sub-coring of embayment samples for the ancillary gear area study (Appendix F). The increased handling and processing for identification of 3 sub-cores for 192 stations or 50.2% of the total samples collected also introduced complexity and concern for data quality.

Edition 5 of the SCAMIT Species list (Southern California Association of Marine Invertebrate Taxonomists 2008) was used by all the taxonomists for this survey work to standardize the taxonomic nomenclature. However, 11 % of the species reported for Bight'08 were previously undescribed and were assigned provisional names. A lack of taxonomic knowledge in estuarine and deep basin environments by taxonomists that don't routinely work in those areas may have contributed to the proliferation of provisional names.

Twenty five taxonomists in five teams identified the 179,338 individual organisms collected during Bight'08. While this was the largest number of taxonomists participating in a regional Bight survey, it was also the smallest number of teams. Seventeeen of the 25 taxonomists had worked on previous surveys. A few very experienced taxonomists worked on more than one team. The species-level identification success was achieved despite the participation of taxonomists with different levels of expertise and differences of opinion. Ranasinghe *et al.* (2003b) demonstrated that different taxonomists produce slightly varying accounts of the taxa present in samples of identical composition; they detected errors in 13.0% of the data records, affecting total abundance by 2.1%, numbers of taxa by 3.4%, and identification accuracy by 4.7%. The condition of specimens (damaged, fragmented, juvenile) also contributes to data quality.

Three groups of organisms were selected for identification and enumeration by specialty taxonomists. There have historically been discrepancies and inconsistencies in nomenclature of these groups amongst taxonomists in previous surveys and specialist identifications eliminated some of the data combination (taxon lumping) that was necessary in past surveys due to inconsistencies and uncertainties. The specialists also produced keys and conducted workshops under the aegis of SCAMIT, distributing the consolidated knowledge accumulated by processing all the SCB specimens in these challenging groups collected during Bight'08. The groups that were selected were Cnidaria, Enopla Nemertea, and Syllidae Polychaeta.

To aid the Bight'08 taxonomists in their identification work, as in the previous surveys, a list-server was set up for the taxonomists to post messages, send digital images to each other of encountered unusual specimens, and request information or assistance. Before and during Bight'08 identification and enumeration, SCAMIT devoted several meetings to review of common species of different taxon groups that would be most likely encountered in the survey. All taxonomists that worked on the Bight'08 survey are members of SCAMIT and were required to participate in the meetings.

Data Submission and Time Line

After completion of sample processing by each lab, results were submitted electronically based on formats stipulated in the Bight'08 Information Management Plan. The web-based data submission tool that was used successfully for Bight'03 was improved and used by each lab to submit their benthic data. The tool facilitates compliance with nomenclatural standards and the 5th Edition of the SCAMIT Species List (Southern California Association of Marine Invertebrate Taxonomists 2008). At submission, species names not on the SCAMIT list were flagged and lab data managers alerted to facilitate verification before data were finalized. Obsolete nomenclature that was accidentally used was flagged during submission. Every lab submitted an encountered species list with their data that was also checked for nomenclatural violations. This process proved very successful at identifying nomenclatural errors and facilitated combination of data from the five labs.

Although initial data submissions were completed only in August 2010, five months after the March 2010 target date, the synoptic data review and quality assurance re-analysis were completed by October 2010, within a month of the September 2010 target date. Significant progress in reducing the time for initial data submission was made from Bight'98 to Bight'03, from 24 to 13 months after sampling, and relaxed to 18 months (March 2010) for Bight'08. Despite this delay, efficiencies created by automated re-analysis data submission, discrepancy identification, and synoptic data review list generation as well as a substantially improved re-analysis procedure resulted in completion of these processes within a month of the September 2010 target. The Bight'08 benthic report is being released 41 months after sampling completion (February 2012), while the Bight'98 and Bight'03 reports were released 54 and 44 months after sampling completion, respectively. Release of both previous reports was delayed by the need to develop benthic assessment methods for new habitats in order to assess their condition.

Synoptic Data Review

After data from all the teams were combined into a single data set, Bight'08 taxonomists conducted a synoptic data review. The goal of the review was to produce final data that were as consistent and free of taxonomic errors as possible. To achieve this, the data were presented in a form that facilitated taxonomic comparisons. Taxonomists working on the different groups of animals met, identified potential inconsistencies, discussed, and resolved species reporting patterns potentially due to uneven distribution of knowledge, or levels of taxonomic expertise. Planktonic and parasitic species were eliminated. Decisions resolving the inconsistencies were applied to the submitted data to produce the final data set.

One of the consequences of the synoptic data review is the combination of taxa to higher taxonomic categories where inconsistencies at a lower level cannot be satisfactorily resolved. In Bight'08, 30 taxa were combined into eight higher taxonomic categories (Table III-8), a substantial improvement over previous surveys. In Bight'98, more than 57 taxa were combined into 19 higher categories, while more than 42 taxa were combined into 13 higher categories for Bight'03. The Bight'08 combinations were only at the genus and family levels, while Bight'98 and Bight'03 each included two combinations at the order taxonomic level.

Table III-8. Changes in Levels of Identification after the Synoptic Data Review

Group	Name Adopted After Synoptic Data Review	Level	Number of Taxa Combined
PHYLUM MOLLUSCA			
Class Gastropoda			
Order Sorbeoconcha	Lirobittium spp.	Genus	5
Order "LowerHeterobranchia"	Turbonilla spp.	Genus	7
PHYLUM ANNELIDA			
Class Polychaeta			
Order Canalipalpata	Aphelochaeta spp.	Genus	6
	Chaetozone spp.	Genus	3
	Monticellina spp.	Genus	3
PHYLUM ARTHROPODA			
Order Amphipoda	Eusirus sp.	Genus	2
	Protohyale spp.	Genus	2
Order Cumacea	Lampropidae	Family	2

Sample Reanalysis to Assess Data Quality

A subset of 38 samples was re-analyzed to evaluate success at meeting identification and enumeration objectives and assess data quality. Ten percent of the samples in each stratum were re-identified and re-enumerated by a second taxonomic team with no access to the original data. Taxonomists that worked on more than one team were not allowed to reanalyze samples they originally identified. The results were compared and discrepancies resolved by the identifying taxonomists. These 38 samples included 28,427 individual organisms or 15.8% of the final data set (Table III-9) and produced 944 discrepancies.

Discrepancies were classified either as true errors or differences, and error rates calculated for each sample as ratios of the difference between the original and resolved values to the resolved values. Discrepancies were classified as true errors when they were caused by inaccurate identifications, incorrect counts, or specimens overlooked in the original analysis. They were classified as differences, rather than errors, when they resulted from the use of a junior synonym or other unconventional nomenclature, apparent specimen loss or differences of opinion about the taxonomic level to which an organism could be identified. The resolved values represented the "truth" by consensus among the original and re-analyzing taxonomists. For this survey a new additional metric was used to assess identification error with relation to individual abundance. This proved particularly useful when assessing samples with low diversity but high abundance as is often the case with estuarine samples. In previous Bight surveys only the number of taxa missed was used to assess identification error rate. In other words, mis-identifying two individuals of one taxon was previously counted the same as mis-identifying 20 individuals of the same taxon. Weighting by abundance provides a better assessment of identification accuracy because consistency is a major component of taxonomy.

The average performance of all five labs met the MQO for all four metrics (Table III-9). However, three labs were slightly over the 10% error rate for the number of taxa changed, most likely due to the numerous and challenging bay and estuary samples; these labs processed the largest number of bay and estuary samples and, therefore, had the most sub-cores to contend with. Low abundances of organisms present in the small sub-cores also made it easier to fail the MQO by magnifying the percentage represented by each organism.

Table III-9. Means (and ranges) of error rates for total abundance, numbers of taxa, and identification accuracy.

Lab	Samples	Organisms	Total Abundance (MQO ≤ 10)	Number of Taxa (MQO ≤ 10)	Identification Accuracy	
					Taxa changed	Individuals misidentified
A	16	17,724	2.15 (0 – 9.8)	4.13 (0 – 12.8)	10.8 (0 – 29)	6.95 (1 – 33.3)
B	8	1529	1.9 (0 – 7.8)	3.7 (0 - 13)	6.15 (3.1 – 10.2)	6.75 (3.2 – 11.1)
C	5	2231	3.09 (0 – 6.4)	4.08 (0 – 8)	8.06 (0 – 15.2)	5.98 (1.1 – 13.5)
D	5	1975	2.67 (0 – 6.7)	5.12 (0.9 – 8.3)	10.15 (4.2 – 16.7)	8.33 (1.5 – 15.4)
E	4	4968	2.55 (0.2 – 5.5)	7.85 (3.9 – 11.1)	10.72 (6.7 – 13.6)	3.93 (1.9 – 8.79)
All	**38**	**28,427**	**2.47 (0 – 9.8)**	**4.98 (0 – 12.8)**	**9.18 (0 – 29)**	**6.39 (1 – 33.3)**

The 944 discrepancies identified during re-analysis were analyzed to pinpoint changes that could result in future improvements in identification accuracy. True misidentification errors by the primary taxonomist accounted for 22% of all the discrepancies (Table III-10), while miscounts accounted for 20.9%. Different levels of expertise and judgmental differences between taxonomists accounted for 25.9% of the discrepancies. Experience and increased training is the best way to reduce these error percentages. Active SCAMIT participation and individual laboratory focused efforts at internal QA/QC protocols would be very beneficial for future surveys. Data entry and keypunch discrepancies were only 0.6% due to the electronic data submissions, species list verification checks and the diligent efforts of laboratory data managers. Probably the category that could most easily be improved upon is vouchering (16.4%), either forgetting to remove the specimen from the sample or forgetting to report its removal as a voucher. The overall vouchering process could also use improvements for the next regional survey. A total of 92 specimens (9.7%) were presumed lost during the reanalysis rather than miscounted. This may be inaccurate but is difficult to assess and some portion may be due to over counts by the primary taxonomist. Nineteen (50%) of the reanalyzed samples were stations with sub-cores that had to be individually processed by the taxonomists. With three times as many vials to handle for those stations, the chance of losing specimens greatly increased.

Table III-10 QA/QC Reanalysis Discrepancies by Categories

Category	Definition/Description	Percentage
True Misidentification	By primary taxonomist	22.0
Miscounts	By primary taxonomist	20.9
Level of Expertise	Variation between primary and re-analysis taxonomist	25.9
	Convention difference	1.7
	Organism too small to speciate	0.6
Processing	Unreported voucher specimen	16.4
	Presumed lost	9.7
	Overlooked vial	0.5
	Organism added from another vial	0.5
Specimen condition	Damaged, fragmented, dead when collected	0.8
Data Entry	By either taxonomist or keypunch operator	0.6
Undetermined		0.4
Total		100.0

The re-analysis process was successfully streamlined and simplified for Bight'08, with discrepancies analyzed for all 38 randomly selected samples (10% of the 382 sample total) and taking reduced time for reanalysis. For Bight'98 and Bight'03, only 27 and 30 samples (8.7% and 7% of the total), respectively, were successfully reanalyzed. Previously, all teams participated in re-analysis and every team checked at least 10% of another teams original work. For Bight'08, re-analysis was restricted to two teams to tighten and speed up the reanalysis process and reduce paperwork dispersion. With only two teams doing the reanalysis, only three meetings at two laboratories were necessary for resolution of discrepancies. Paperwork for the resolution reports was minimized and restricted to the re-analyzing teams of taxonomists, which made it easier to interpret and track. Geographically, the redistribution of the 38 samples was also simplified. Another new feature was the inclusion of re-analysis results in the automated data submission system, which substantially reduced the time and effort required for identification and compilation of discrepancies.

Discussion

The challenge of producing and verifying an accurate and internally consistent description of the species composition of benthic macrofaunal communities over a wide range of habitats and depths was considerable. The necessity of relying on a large number of taxonomists added to the complexity of the task and the introduction of sub-cores for half the samples also complicated the overall process. However, measures to coordinate and standardize taxonomic practices effectively met these challenges.

In this survey, we provided species-level identifications for 83.3% of the specimens that were collected, an increase of 7% from Bight'03. A total of 1,734 taxa were reported which is 70 more than Bight'03. There were three reasons for this improvement. First, SCAMIT has continued to use problems discovered in Bight surveys to focus its activities in the period between surveys. Keys and other identification aids were produced for many problem taxa from previous regional surveys, facilitating consistent treatment in the Bight'08 survey. Second, specialty taxonomists processed three groups of organisms that presented obstacles to consistent treatment despite standardization efforts. The specialty taxonomist treatment of the Cnidaria, Enopla Nemertea, and Syllidae Polychaeta separated 143 taxa that present special challenges regionally. This greatly improved the data. However, the third and largest contributing factor to this improvement is related to the fact that 15 of the 25 taxonomists involved have worked on all four regional surveys.

While the majority of the measurement quality objectives (MQOs) were met as overall averages and individual laboratory averages, a small number of samples failed to achieve the objectives for sorting and number of taxa changed by a small margin. These failures resulted from the lack of experienced sorters and identification discrepancies made in samples with low abundance and diversity, such as those from very shallow estuarine habitats and deep slope and basin habitats. Just a few errors on samples with few individuals have a big impact on quality assurance and quality control measures. However, the ability of most teams to reach the established MQOs, as well as their performance in previous regional surveys indicates that the MQOs are reasonable and achievable.

Logistic Recommendations

Our results demonstrate that Bight'08 data are of very high quality. In addition there were several substantial improvements in data processing and submission that shortened the time between field sampling and final data submission. However, there are still challenges evident in our failure to meet major time lines, and quality controls related to sorting as well as the number of taxon names changed for identification accuracy. Performance to achieve these goals can be improved by implementing the following recommendations in future regional surveys.

1. **Include Museum personnel during planning activities.** Depositing specimens collected in Bight regional monitoring programs in the Natural History Museum of Los Angeles County (NHMLAC) is a major step forward and activities to facilitate this process should continue and be enhanced. Beginning with Bight'03, specimens were deposited in the

museum for preservation and long-term taxonomic contributions to posterity. Including museum personnel during planning activities, standardizing glassware and voucher and vial labels in advance, and including more specifics on vouchering procedures in the lab manual would streamline and improve the acquisition process. In addition, acquisition of voucher specimens could be improved by laboratory reports, verification checks of identity, laboratory verification that all vouchers are removed from the reanalysis samples prior to redistribution. Voucher specimens should not be included in discrepancy reports and re-analysis taxonomists should assume that all vouchers have been removed from samples.

2. **Shorten the analysis timeline.** Efforts should be made to shorten the time interval between sample collection and data submission. Competing priorities for participating teams resulted in delays during Bight'98, Bight'03 and again in Bight'08. Because several steps in the production of a final data set require completion of sample processing and data submissions by all teams, delays by one team affect the others. Significant progress was made from Bight'98 to Bight'03, and the time for initial data submissions reduced from 24 to 13 months after sampling. For Bight'08, the target was relaxed to 18 months, but initial submissions were completed only after 24 months. However, efficiencies achieved by improved quality assurance sample reanalysis and synoptic data review processes resulted in completion in October 2010, within a month of the September 2010 target date. Shortening the time interval for sample analysis will speed release of regional monitoring reports and increase their management and societal relevance. However, achieving this may be a challenge because, as a survey conducted by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) clearly showed, we are in a crisis of losing the majority of our trained macroinvertebrate taxonomists within the next ten years, and few taxonomists are being trained to replace them.

3. **Continue using regional survey results to focus SCAMIT activities**. The reduction in taxa combined (lumped) due to unshared taxonomic knowledge is directly attributable to SCAMIT activities between Bight'03 and Bight'08. These efforts drew upon the results of quality control and quality assurance efforts in previous regional surveys. This model should continue to be pursued in the future. Supporting and promoting active participation in SCAMIT by taxonomists within the region will continue to be essential to the success of future surveys.

4. **Continue using specialty taxonomists.** Taxonomic specialization should continue as a means of ensuring consistent treatment of problematic groups. The present practice of producing diagnostic keys and presenting them at SCAMIT meetings to facilitate consistent treatment by other taxonomists in the future should also continue.

5. **Revise the sample re-analysis data assessment procedure.** The Bight'08 approach of using only 2 teams to re-analyze 10% of the samples was a big improvement over past surveys in completeness of the quality assurance procedure. However, centralizing the role of re-analytical lab, discrepancy tabulation and resolution around a single team not involved in the original analysis should be considered.

IV. DESCRIPTIVE RESULTS

Introduction

The purpose of this chapter is to compare and contrast community measures and dominant higher taxonomic groups and species in the habitats of the Southern California Bight (SCB) during summer 2008, in relation to the ecological and environmental characteristics and settings of the habitats. The habitats differ in magnitude of exposure to terrestrial, freshwater discharges, and human influences. Embayments, including estuary and bay habitats, are in close proximity to these disturbance sources and consequently have high exposure. The offshore mainland shelf, island shelf, and slope and basin habitats are situated at increasing distances away from these sources.

Community measures provide information about the structure and composition of the assemblages. Shannon-Wiener diversity, Pielou's evenness, and Swartz's dominance measure the distribution of abundance across species, which usually reflects the magnitude of environmental stress. Often large numbers of one or two species are present in highly stressed habitats and these tolerant forms dominate resources and sustain large populations. Shannon-Wiener species diversity is a measure of information content of each organism. In areas where many species coexist, and individuals are fairly evenly distributed among them, Shannon diversity and evenness are high. In situations where few species exist in high numbers, Shannon diversity, and evenness are low. Dominance integrates diversity and evenness and measures the minimum number of species with combined abundance equal to 75% of the individuals in the sample. It is an inverse measure, so highly dominated communities have a low score, usually indicating high stress, and evenly distributed communities with lower stress have a high score.

Biodiversity measured as taxon richness or Shannon diversity is often considered an indicator of community health and sites with fewer species are considered to be in more stressful environments than those with many species (Weisberg *et al.* 2008, Teixeira *et al.* 2010, Thompson *et al.* 2012). However, the distribution of biodiversity along some environmental gradients is not quite so clear. For instance, in relation to organic enrichment, numbers of species often peak in regions of intermediate disturbance, declining both in unaffected and more highly affected areas (Pearson and Rosenberg 1978). The number of species in a sample is also related to the degree of stress in each habitat, but is a relative measure that also varies in response to natural conditions unrelated to stress.

Total abundance of organisms in benthic samples is a highly variable community measure and provides little interpretable information, except at the extremes. Samples with low abundances are usually subject to natural or anthropogenic stress, while samples with high abundances and unbalanced, highly dominated distributions are usually subject to eutrophication due to excess nutrient loadings.

Similarities and differences in the higher taxa and species that dominate habitats also reflect environmental similarities and differences. Few previous studies have sampled such a wide range of Southern California Bight habitats as intensively as the Bight'08 Regional Monitoring Program and these results provide new information and insights in habitats little studied in the past, such as the estuary, and slope and basin habitats.

Methods

Descriptions are presented for the five embayment and offshore habitats where benthic macrofauna were sampled during the Bight'08 regional monitoring survey: (1) estuaries, (2) bays, (3) the mainland shelf, (4) the Channel Island shelf, and (5) the slope and basin habitat. Three types of measures were calculated for each habitat. First, five community measures were calculated for each sample and area-weighted means were computed for each habitat: (1) total abundance, (2) number of taxa, (3) the Shannon-Wiener Diversity Index (Pielou 1969), (4) Evenness (Pielou 1969), and (5) Dominance (Swartz *et al.* 1986). Shannon-Wiener Diversity was calculated using natural logarithms. Evenness, which is the ratio of the observed Shannon-Wiener Diversity to the maximum given the same number of taxa (Pielou 1969), was also calculated using $\log_e$. Dominance was calculated as the minimum number of species with combined abundance equal to 75% of the individuals in the sample (Swartz *et al.* 1986). The area weights were used to adjust overall means for the different areal extents represented by different samples.

Second, area-weighted species abundances were summed by higher taxonomic groups and dominant groups were expressed as percentages of total abundance and compared among habitats. Finally, three measures were compared across habitats for the ten most abundant taxa in each habitat: (1) abundance rank, (2) mean abundance per sample, and (3) the percentage of sampling sites where the taxon occurred. For abundance rank calculations, ranks for tied abundances were assigned as means of the corresponding values.

Results

Biodiversity as measured by species richness (number of taxa) and Shannon diversity was highest on the Channel Island shelf (Table IV-1). Channel Island shelf species richness was about 1.5 times species richness on the mainland shelf, and more than twice that of the other habitats. Biodiversity was intermediate in bays and lowest in slopes and basins and estuaries.

Evenness was highest and similar in the three offshore habitats, intermediate in bays, and lowest in estuaries (Table IV-1). Of the three offshore habitats, evenness was highest on the slopes and in basins, which are characterized by fewer species and fewer individuals; many species were represented by single individuals. Evenness was lowest in the estuaries, with a few very abundant species mixed with other species with lower abundance.

The five habitats showed a variety of dominance structures. The most heavily dominated communities were found in the estuaries, with only five species contributing 75% of the individuals. The Channel Island shelf habitat was at the other dominance extreme, with nearly 36 species required to make up 75% of the community. The mainland shelf stratum was second in dominance with an average of 27.4 species, followed by bays with 14.5 species and the slopes and basins with 9.7 species.

Mean abundance was highest in estuaries, the Channel Island shelf, and bays (Table IV-1), and next on the mainland shelf at about half the mean abundance of the first three habitats. Mean abundance of slopes and basins was lowest, and about an eighth of the mainland shelf.

Polychaete worms, amphipod crustaceans, and bivalve molluscs dominated all five habitats. Polychaete worms were most abundant in all five habitats and accounted for more than half of benthic abundance in all but the slope and basin habitat (Table IV-2). In the slope and basin habitat, polychaetes accounted for nearly half (41.1%) of the abundance and bivalve molluscs were especially abundant, and comprising 22.4% of the encountered organisms. Amphipod crustaceans were second or third most abundant in all five habitats and contributed 10.6-16.0% of abundance. Bivalve molluscs replaced amphipods as the secondmost abundant taxonomic group in the slope and basin habitat.

Ophiuroid echinoderms contributed more abundance in offshore habitats (4.2-9.7%) than in embayments (1.3%). In contrast, oligochaete worms and gastropod molluscs were more prevalent in embayments than in offshore habitats, and most prevalent in estuaries. In estuaries, the percentage abundances of oligochaetes and gastropods were more than ten times and one and one half times the percentages in any other habitat, respectively.

Of the ten most abundant and prevalent species in the Southern California Bight, two, *Mediomastus* spp. and *Exogone lourei*, were widespread and abundant in four of the five habitats (Tables IV-3, IV-4, and IV-5). Both had lowest abundance ranks, abundances, and occurrences in the slope and basin habitat.

The other eight top ten species were primarily embayment species with highest abundances, abundance ranks, and occurrences in embayments. Five of the eight species, *Pseudopolydora paucibranchiata, Fabricinuda limnicola, Grandidierella japonica, Musculista senhousia,* and *Barleeia* spp. were abundant and prevalent in both estuaries and bays. The most abundant species overall, *Polydora nuchalis,* was the most abundant estuarine species and occurred almost exclusively in estuaries. *Amphideutopus oculatus* was the most abundant and prevalent bay species, but it also occurred at 20.9% of the mainland shelf sampling sites. Oligochaeta had high abundance and high occurrence in estuaries and bays, but also occurred in offshore habitats, particularly the Channel Island shelf. These organisms are presently identified only at the class level and it is likely that identification to genus and species would enhance the habitat specificity of abundance distributions.

Of the nine species comprising the three most abundant species in the three offshore habitats, only *Mediomastus* spp., one of the two widespread dominants, was ranked in the top ten abundances bight-wide. *Amphiodia urtica* and *Spiophanes norrisi* were most abundant on the mainland shelf, but ranked 25th and 31st bight-wide. More than half the sites at which *A. urtica* occurred were on the mainland shelf (Table IV-4), where it dominates the community (Barnard and Ziesenhenne 1960). Both species ranked in the top 31 on the Channel Islands shelf, but occurred there in lower abundances. *Laphania boecki,* the most abundant Channel Islands species ranked 33rd bight-wide, but occurred at only 10% of Channel Island shelf sampling sites and was not collected in any of the other habitats. *Leptochelia dubia* ranked second in Channel Island abundance, 19th in bight-wide abundance, and occurred in reduced numbers (Table IV-5) and at fewer sites (Table IV-4) in the other four habitats. *Amphipholis pugetana* ranked third in Channel Island shelf abundance and 55th bight-wide, and occurred mainly on the Channel Island shelf.

The dominant macrofauna of the slope and basin habitat were largely unique. None of the ten most abundant species in this habitat were ranked in the top ten bight-wide, and ranks, abundances, and occurrences in other habitats were low. *Maldane sarsi*, *Dacrydium pacificum*, and *Macoma carlottensis*, the three most abundant slope and basin species ranked 93rd, 147th, and 203rd bight-wide (Table IV-3).

Discussion

This diversity of Southern California Bight benthic habitats represented by the 382 spatially random samples collected for this study is unprecedented. The samples represented 16,782 km^2 of benthic habitat ranging from embayments that include shallow estuaries and bays, across the offshore continental and island shelves, and down continental slopes to basins at a depth of 1,000m. The study includes much the same area as Ranasinghe *et al.* (2007) but substantially increases the extent and intensity of estuarine sampling. Previous regional benthic monitoring studies (Bergen *et al.* 1998, Bergen *et al.* 2001, Ranasinghe *et al.* 2003a) sampled the same region, but included only a few of the habitats included here. Many other benthic studies have been conducted within the region, but their spatial extent and the range of habitats sampled were limited. Most of these investigations provide data on the mainland shelf, some involving repeated occupations of the same sites over 40 years or more.

Our study included three offshore habitats and two embayment habitats. Two of the three offshore habitats, the Channel Island shelf and the Mainland shelf, had diverse, abundant, evenly distributed, and undominated communities. These characteristics are usually associated with unstressed or undisturbed communities. The Channel Island shelf had the highest species richness, Shannon Diversity, Evenness and Dominance, while mainland shelf communities were less diverse and less abundant with similar evenness values. In contrast, the deeper slope and basin communities inhabiting the third offshore habitat were depauperate with low abundances and low biodiversity, which are potentially indicative of depleted resources or stress. However, the slope and basin communities also had the highest evenness, which is usually associated with low stress and an absence of disturbance. In the two strata with greatest organic and toxicant loading (Schiff *et al.* 2011), the estuaries and the slope and basin habitat, numbers of species were lower than in other strata.

The two embayment habitats, estuaries and bays, both had low biodiversity, low evenness, and highly dominated communities in keeping with their proximity to terrestrial, freshwater discharge, and human activity. Estuaries are all natural, but degraded to varying extents. Of the sampled bays, some were natural and others were man-made, but all were heavily modified by human use even if they were not constructed by man.

The Channel Island shelf communities (5-200 m deep) had the highest species richness, Shannon Diversity, Evenness and Dominance, reflecting diverse and evenly distributed fauna living in a well oxygenated, complex bottom environment with a multitude of niches not widely available on the mainland shelf. The animals living on the shelves surrounding the islands have a much different habitat than the mainland shelf. One of the primary differences is in grain size of the sediments, which tend to be coarser because hardly any fine material is added from erosion of the islands, and particles from the mainland settle before they reach the islands. The bottom often has a strong biogenic component, comprising fragments of barnacles, mollusk shells, sea-urchin spines, and bryozoans, which are contributed by the attached biota of submerged rocky outcrops. The animals detach from the rocks after death and fragment to form the bottom sediments.

The rich diversity and even distribution of island shelf fauna also reflects oxygen rich conditions and abundant larval settlement relative to the mainland shelf. The complex bottom topography created by rocky outcrops results in strong currents and high bottom water oxygenation. Because they are exposed to the southward flowing California Current to the west and the northward flowing Davidson Counter Current to the east, they offer two separate thermal regimes and larval supply pathways adding to the richness of the biota living on them.

The Channel Islands fauna included a mix of unique and widespread fauna. Two of the five most abundant species, *Laphania boecki* and *Amphipholis pugetana*, occurred almost solely in the Channel Islands, while the others, *Leptochelia dubia*, *Mediomastus* spp., and *Exogone lourei*, were more widespread.

The Mainland Shelf communities (≤200 m deep) were second to the Channel Island shelf in biodiversity and even distribution of fauna. They are closer than the island shelf or the slopes and basins to terrestrial particulate inputs from natural and anthropogenic sources, which provide organic inputs and serve as food. They are also closer to other less favorable inputs of toxic materials, freshwater, and debris. There is a general gradient of decreasing water motion with increasing depth along the mainland shelf. Water temperature decreases and grain size becomes finer as depth increases.

The five most abundant mainland shelf taxa, *Amphiodia urtica*, *Spiophanes norrisi*, *Mediomastus* spp., *Spiophanes berkeleyorum*, and *Amphiodia* spp., were shared with other habitats, most often the Channel Islands. Comparison of our results with previous studies (Hartman 1955, 1966, Jones 1969, Fauchald and Jones 1978, Thompson *et al.* 1993a, Ranasinghe *et al.* 2007) indicate that the same taxa have dominated the mainland shelf over at least the last five decades.

The slope and basin communities (200-1000 m deep) had much lower faunal abundance and taxon richness than any other habitat, although abundance was evenly distributed among species. The animals that reside here differ from those of the other habitats, with only two of the ten most abundant species, *Paraprionospio alata* and *Spiophanes kimballi*, ranked in the top 70 in any other habitat. The polychaete worms that dominate the embayment and shelf habitats are less dominant in the slope and basin habitat and their ecological role is largely taken over at greater depths by prochaetodermatid mollusks on abyssal plains (Scheltema 1997). The megabiota of slope and basin habitat is dominated by echinoderms of several types (Allen *et al.* 2007), but there is little evidence of them in the infauna.

Similar decreases in benthic abundance and species richness as depth increased from shelf through slope to basin habitats were previously reported by Hartman and Barnard (Hartman and Barnard 1958, 1960), Fauchald and Jones (1978) and Thompson *et al.* (1993a). The dominant slope and basin species reported by these authors, and by Hartman (Hartman 1955, 1963, 1966) include all ten of the slope and basin habitat dominants identified in our study.

The lower abundance and faunal richness of the slope and basin habitat are likely due to low oxygen concentrations and, while food is available, it is often limiting. Physical conditions on the upper slope often include ample food and adequate oxygenation, while the soft bottom of the slope and basin habitat are almost uniformly covered with fine sediments (primarily silts and clays). The oxygen minimum zone (OMZ) usually resides within the slope and basin habitat, which is a challenge for most species. The OMZ is dominated by species that thrive under low oxygen conditions (Cimberg *et al.* 1993, Levin *et al.* 2001). Within the basins, oxygenation is even lower. Some of the basins are anoxic for long periods, and all sill-surrounded enclosed basins are always hypoxic. As our results show, the density of animal life in these areas is usually very low, while within the OMZ there may be high density populations of tolerant species.

Under these low temperature and oxygen conditions the fauna tends to be smaller than in other habitats and many of these smaller individuals likely pass through sieves used to capture macrofauna. Approximately 15% of the slope and basin species are too small to be retained on the 1 mm screens used in our study (unpublished data). The naturally low density and diversity biota of this habitat may be further reduced by this sampling bias.

Unlike the offshore habitats, the two embayment habitats, estuaries and bays, had low biodiversity, low evenness, and highly dominated communities. The estuaries had the lowest Shannon Wiener diversity and evenness, and were the most highly dominated habitat. Only 5.4 species comprised 75% of the abundance despite having the highest average abundance of any habitat. The high abundance likely reflects food availability in the high carbon estuarine environment. The low diversity, highly dominated communities in estuaries likely reflect seasonal freshwater inflows and proximity to centers of human activity. Southern California estuaries represent the remnants of a much larger habitat now largely destroyed by man's activities, having been filled in to allow construction of residential areas. Our lists of dominant soft-bottom embayment benthic species correspond well with results of previous studies (Thompson *et al.* 1993a).

In the SCB, estuaries are of limited extent, and many are seasonal. Estuaries have well developed salinity gradients, but these gradients are often very short or even absent for long periods due to the Mediterranean climate and sporadic rainfall. Oligochaete worms, which tend to be diverse and abundant in areas of reduced salinity, are more abundant in estuaries than in any other habitat. In their shallower portions, estuaries usually support dense plant cover, adding a food resource not often available in other habitats. The elevated abundances of gastropods, many of them grazing herbivores, reflect this food source. *Polydora nuchalis*, the most abundant organism in the SCB, was encountered almost exclusively in estuaries. All but one of the other top ten dominant species was shared with bays and other habitats. The other exclusively estuarine dominant was *Tryonia imitator*, a gastropod mollusk that was ranked sixth.

Bays, either natural or man created, tend to support a different community of infaunal organisms than estuaries. Only three of the ten most abundant bay species were among the ten most abundant in estuaries (Table IV-1). This is primarily due to the differences between bays and estuaries in depth, bottom type, sediment stability, and physical water quality (current, temperature, oxygenation, suspended particulates) parameters. Bays are also continually modified through human activity, especially by maintenance dredging to support vessel movement. Estuaries are most heavily affected by indirect, run-off related inputs of organics and toxicants, while bays are most affected by direct manipulation of their structure and vessel related toxic inputs. Bays also support "hard-bottom" substrate provided by man-made structures, which are lacking in estuaries and most of the continental shelf. Larval inputs from the fouling community in bays also modify the bottom community, introducing a broader diversity of species. The ten most abundant bay species were common in other habitats, most often estuaries.

Overall, the species that dominate the benthic macrofauna of the five Southern California Bight habitats differ from habitat to habitat. The benthic assemblages also differ in biodiversity and evenness of abundance distribution among the species that are present. These differences reflect the environmental diversity of the habitats, which give rise to the observed biological differences. Comparisons of our results with previous studies indicated that the same species have dominated the five southern California soft-bottom benthic habitats for over five decades.

Table IV-1. Area-weighted benthic community measure means and standard errors for Southern California Bight habitats. Abundances and number of taxa are for 0.1-m^2 Van Veen grab samples. The Shannon-Wiener Diversity Index (Shannon) was calculated using $\log_e$; therefore, the units are nats. Evenness is the ratio of the observed Shannon diversity to the maximum, given the same no. of taxa (Pielou 1969). Dominance is the minimum number of species whose combined abundance is equal to 75% of the individuals in the sample (Swartz *et al.* 1986).

Habitat	Samples	Abundance	No. of taxa	Shannon Wiener Diversity	Evenness	Dominance
Estuaries	64	793.4 ±123.97	30.8 ±2.49	1.94 ±0.092	0.60 ±0.018	5.4 ±0.61
Bays	128	550.7 ±43.19	56.4 ±1.89	3.03 ±0.050	0.76 ±0.010	14.5 ±0.82
Mainland Shelf	90	346.3 ±22.01	85.4 ±3.53	3.63 ±0.058	0.83 ±0.009	27.4 ±1.11
Channel Island Shelf	30	646.4 ±128.66	122.4 ±8.10	3.93 ±0.086	0.83 ±0.013	35.8 ±2.74
Slope and Basin	70	45.8 ±5.53	19.0 ±1.44	2.37 ±0.100	0.85 ±0.022	9.7 ±0.73

Table IV-2. Area-weighted percentage of benthic abundance contributed by the most abundant higher taxa in the Southern California Bight and its habitats.

HigherTaxon	Southern California Bight	Estuaries	Bays	Mainland Shelf	Channel Island Shelf	Slope and Basin
Annelida : Polychaeta	50.8	54.9	50.5	54.6	50.3	41.1
Arthropoda : Amphipoda	13.9	13.9	15.8	13.0	16.0	10.6
Mollusca : Bivalvia	10.6	6.5	13.8	8.2	8.5	22.4
Echinodermata : Ophiuroidea	7.2	1.3	1.3	9.7	6.0	4.2
Mollusca : Gastropoda	2.4	7.5	4.5	1.9	2.5	3.5
Arthropoda : Tanaidacea	2.4	0.6	2.9	1.0	4.7	0.4
Arthropoda : Ostracoda	2.1	0.6	2.4	2.5	1.6	1.9
Nemertea	1.6	0.6	0.7	1.6	1.5	1.9
Arthropoda : Cumacea	1.2	1.0	0.2	1.5	0.6	2.2
Arthropoda : Isopoda	1.1	1.0	2.1	1.1	1.2	0.8
Annelida : Oligochaeta	0.2	9.3	0.7	0.0	0.4	0.1

Table IV-3. Abundance ranks for the ten most abundant species in each habitat. Occur.: Frequency of occurrence; Est.: Estuaries; Islands: Channel Island shelf.

Species	Higher Taxon	Overall				Abundance Rank by Habitat				
		Abundance Rank	Abundance $(0.1\ m^{-2})$	Abundance (%)	Occur. (%)	Est.	Bays	Mainland shelf	Islands	Slope and Basin
Polydora nuchalis	Annelida : Polychaeta	1	26.58	5.67	5.8	1	604.5			
Mediomastus spp.	Annelida : Polychaeta	2	19.45	4.15	59.7	4	6	3	5	110
Exogone lourei	Annelida : Polychaeta	3	18.28	3.90	32.5	24	1	34.5	4	161
Pseudopolydora paucibranchiata	Annelida : Polychaeta	4	17.35	3.70	32.5	7	2			
Fabricinuda limnicola	Annelida : Polychaeta	5	14.62	3.12	12.3	8	4	875.5		
Grandidierella japonica	Arthropoda : Amphipoda	6	14.48	3.09	20.2	2	29			
Musculista senhousia	Mollusca : Bivalvia	7	12.42	2.65	23.3	25	3			
Barleeia spp.	Mollusca : Gastropoda	8	11.37	2.42	6.3	14	5			
Oligochaeta	Annelida : Oligochaeta	9	11.00	2.34	25.4	3	14	702	49.5	201.5
Amphideutopus oculatus	Arthropoda : Amphipoda	10	8.58	1.83	29.6	111	7	42.5	809	
Leitoscoloplos pugettensis	Annelida : Polychaeta	11	7.84	1.67	38.5	33	8	118	317.5	201.5
Theora lubrica	Mollusca : Bivalvia	12	7.59	1.62	32.5	17	10			
Scoletoma sp C	Annelida : Polychaeta	13	6.63	1.41	30.1	35	9			
Acteocina inculta	Mollusca : Gastropoda	14	6.40	1.36	20.9	9	23	702		
Capitella capitata Complex	Annelida : Polychaeta	15	6.17	1.32	14.9	5	51	498	260.5	
Euphilomedes carcharodonta	Arthropoda : Ostracoda	17	5.57	1.19	38.7	63	11	9	54.5	35.5
Tryonia imitator	Mollusca : Gastropoda	18	5.41	1.15	6.0	6				
Leptochelia dubia	Arthropoda : Tanaidacea	19	4.53	0.96	26.7	49	26	23	2	124.5
Spiophanes duplex	Annelida : Polychaeta	20	4.33	0.92	43.5	41	21	7	54.5	268
Streblospio benedicti	Annelida : Polychaeta	24	3.61	0.77	7.9	10	183.5			
Amphiodia urtica	Echinodermata : Ophiuroidea	25	3.60	0.77	25.7	65	74	1	31	381.5
Spiophanes norrisi	Annelida : Polychaeta	31	3.08	0.66	16.0	326.5	225	2	28	
Laphania boecki	Annelida : Polychaeta	33	2.75	0.59	0.8				1	
Spiophanes berkeleyorum	Annelida : Polychaeta	39	2.29	0.49	29.6		69	4	44.5	96
Monticellina siblina	Annelida : Polychaeta	40	2.21	0.47	20.9		46.5	8	317.5	
Amphiodia spp.	Echinodermata : Ophiuroidea	51	1.61	0.34	19.6	119.5	179.5	5	250	
Owenia collaris	Annelida : Polychaeta	53	1.57	0.33	6.3	93	234	6	317.5	
Photis californica	Arthropoda : Amphipoda	54	1.56	0.33	10.7		200.5	40.5	6	
Amphipholis pugetana	Echinodermata : Ophiuroidea	55	1.52	0.32	3.1			875.5	3	201.5

Table IV-3. Abundance ranks for the ten most abundant species in each habitat. Occur.: Frequency of occurrence; Est.: Estuaries; Islands: Channel Island shelf.

		Overall				Abundance Rank by Habitat				
Species	Higher Taxon	Abundance Rank	Abundance ($0.1\ m^{-2}$)	Abundance (%)	Occur. (%)	Est.	Bays	Mainland shelf	Islands	Slope and Basin
Paraprionospio alata	Annelida : Polychaeta	60	1.34	0.29	34.0		112.5	17	71.5	10
Spiophanes kimballi	Annelida : Polychaeta	64	1.29	0.28	15.7			15	75.5	5
Decamastus gracilis	Annelida : Polychaeta	65	1.28	0.27	13.6		604.5	25.5	9	161
Photis sp	Arthropoda : Amphipoda	69	1.20	0.26	12.3		301.5	83	8	201.5
Sabellaria nanella	Annelida : Polychaeta	73	1.14	0.24	0.5	205.5		10		
Mooreonuphis sp LA1	Annelida : Polychaeta	78	1.05	0.22	1.0				7	
Maldane sarsi	Annelida : Polychaeta	93	0.81	0.17	21.2		604.5	75	110	1
Ampelisca romigi	Arthropoda : Amphipoda	105	0.71	0.15	3.4			336	10	161
Dacrydium pacificum	Mollusca : Bivalvia	146.5	0.46	0.10	1.8					2
Macoma carlottensis	Mollusca : Bivalvia	203	0.31	0.07	6.3			295	384	3
Prionospio (Prionospio) ehlersi	Annelida : Polychaeta	249	0.24	0.05	6.5		429	702		4
Saxicavella pacifica	Mollusca : Bivalvia	272.5	0.21	0.05	4.2			283		8
Fauveliopsis glabra	Annelida : Polychaeta	277	0.21	0.04	3.9				809	6
Eclysippe trilobata	Annelida : Polychaeta	294.5	0.19	0.04	5.8			382.5		9
Yoldiella nana	Mollusca : Bivalvia	303	0.19	0.04	2.6					7

Table IV-4. Frequency of occurrence of the ten most abundant species at sites in each habitat.

Species	Higher Taxon	Overall Abundance Rank	Frequency of Occurrence (%)					
			Overall	Estuaries	Bays	Mainland Shelf	Channel Island Shelf	Slope and Basin
Polydora nuchalis	Annelida : Polychaeta	1.0	5.8	32.8	0.8			
Mediomastus spp.	Annelida : Polychaeta	2.0	59.7	56.3	82.8	65.9	76.7	4.3
Exogone lourei	Annelida : Polychaeta	3.0	32.5	23.4	60.2	19.8	40.0	2.9
Pseudopolydora paucibranchiata	Annelida : Polychaeta	4.0	32.5	51.6	71.1			
Fabricinuda limnicola	Annelida : Polychaeta	5.0	12.3	17.2	27.3	1.1		
Grandidierella japonica	Arthropoda : Amphipoda	6.0	20.2	59.4	30.5			
Musculista senhousia	Mollusca : Bivalvia	7.0	23.3	32.8	53.1			
Barleeia spp.	Mollusca : Gastropoda	8.0	6.3	25.0	6.3			
Oligochaeta	Annelida : Oligochaeta	9.0	25.4	54.7	40.6	2.2	16.7	4.3
Amphideutopus oculatus	Arthropoda : Amphipoda	10.0	29.6	6.3	69.5	20.9	3.3	
Leitoscoloplos pugettensis	Annelida : Polychaeta	11.0	38.5	31.3	85.2	17.6	3.3	1.4
Theora lubrica	Mollusca : Bivalvia	12.0	32.5	23.4	85.2			
Scoletoma sp C	Annelida : Polychaeta	13.0	30.1	26.6	76.6			
Acteocina inculta	Mollusca : Gastropoda	14.0	20.9	60.9	31.3	1.1		
Capitella capitata Cmplx	Annelida : Polychaeta	15.0	14.9	51.6	12.5	5.5	10.0	
Euphilomedes carcharodonta	Arthropoda : Ostracoda	17.0	38.7	9.4	74.2	38.5	33.3	2.9
Tryonia imitator	Mollusca : Gastropoda	18.0	6.0	35.9				
Leptochelia dubia	Arthropoda : Tanaidacea	19.0	26.7	12.5	25.8	38.5	83.3	1.4
Spiophanes duplex	Annelida : Polychaeta	20.0	43.5	20.3	60.9	62.6	53.3	2.9
Streblospio benedicti	Annelida : Polychaeta	24.0	7.9	42.2	2.3			
Amphiodia urtica	Echinodermata : Ophiuroidea	25.0	25.7	1.6	26.6	56.0	36.7	1.4
Spiophanes norrisi	Annelida : Polychaeta	31.0	16.0	1.6	7.0	40.7	46.7	
Laphania boecki	Annelida : Polychaeta	33.0	0.8				10.0	
Spiophanes berkeleyorum	Annelida : Polychaeta	39.0	29.6		23.4	65.9	63.3	5.8
Monticellina siblina	Annelida : Polychaeta	40.0	20.9		27.3	42.9	20.0	
Amphiodia spp.	Echinodermata : Ophiuroidea	51.0	19.6	4.7	11.7	54.9	23.3	
Owenia collaris	Annelida : Polychaeta	53.0	6.3	7.8	5.5	11.0	6.7	
Photis californica	Arthropoda : Amphipoda	54.0	10.7		5.5	26.4	33.3	
Amphipholis pugetana	Echinodermata : Ophiuroidea	55.0	3.1			1.1	30.0	2.9
Paraprionospio alata	Annelida : Polychaeta	60.0	34.0		20.3	72.5	50.0	33.3
Spiophanes kimballi	Annelida : Polychaeta	64.0	15.7			41.8	50.0	10.1

Table IV-4. Frequency of occurrence of the ten most abundant species at sites in each habitat.

Species	Higher Taxon	Overall Abundance Rank	Frequency of Occurrence (%)					
			Overall	Estuaries	Bays	Mainland Shelf	Channel Island Shelf	Slope and Basin
Decamastus gracilis	Annelida : Polychaeta	65.0	13.6		0.8	30.8	66.7	4.3
Photis sp	Arthropoda : Amphipoda	69.0	12.3		3.9	30.8	40.0	2.9
Sabellaria nanella	Annelida : Polychaeta	73.0	0.5	1.6		1.1		
Mooreonuphis sp LA1	Annelida : Polychaeta	78.0	1.0				13.3	
Maldane sarsi	Annelida : Polychaeta	93.0	21.2		0.8	40.7	40.0	44.9
Ampelisca romigi	Arthropoda : Amphipoda	105.0	3.4			3.3	30.0	1.4
Dacrydium pacificum	Mollusca : Bivalvia	146.5	1.8					10.1
Macoma carlottensis	Mollusca : Bivalvia	203.0	6.3			8.8	10.0	18.8
Prionospio (Prionospio) ehlersi	Annelida : Polychaeta	249.0	6.5		0.8	2.2		31.9
Saxicavella pacifica	Mollusca : Bivalvia	272.5	4.2			8.8		11.6
Fauveliopsis glabra	Annelida : Polychaeta	277.0	3.9				3.3	20.3
Eclysippe trilobata	Annelida : Polychaeta	294.5	5.8			6.6		23.2
Yoldiella nana	Mollusca : Bivalvia	303.0	2.6					14.5

Table IV-5. Mean abundance of the ten most abundant species in each habitat.

Species	Higher Taxon	Overall Abundance Rank	Mean abundance (per 0.1 m^2)					
			Overall	Estuaries	Bays	Mainland Shelf	Channel Island Shelf	Slope and Basin
Polydora nuchalis	Annelida : Polychaeta	1.0	26.58	158.66	0.01			
Mediomastus spp.	Annelida : Polychaeta	2.0	19.45	45.19	26.00	8.40	14.63	0.10
Exogone lourei	Annelida : Polychaeta	3.0	18.28	5.81	46.77	1.88	15.00	0.06
Pseudopolydora paucibranchiata	Annelida : Polychaeta	4.0	17.35	28.52	37.51			
Fabricinuda limnicola	Annelida : Polychaeta	5.0	14.62	27.05	30.10	0.01		
Grandidierella japonica	Arthropoda : Amphipoda	6.0	14.48	76.16	5.13			
Musculista senhousia	Mollusca : Bivalvia	7.0	12.42	5.73	34.21			
Barleeia spp.	Mollusca : Gastropoda	8.0	11.37	11.97	27.95			
Oligochaeta	Annelida : Oligochaeta	9.0	11.00	47.14	8.60	0.02	2.60	0.04
Amphideutopus oculatus	Arthropoda : Amphipoda	10.0	8.58	0.31	24.27	1.66	0.03	
Leitoscoloplos pugettensis	Annelida : Polychaeta	11.0	7.84	3.16	21.30	0.59	0.33	0.04
Theora lubrica	Mollusca : Bivalvia	12.0	7.59	9.64	17.83			
Scoletoma sp C	Annelida : Polychaeta	13.0	6.63	2.84	18.36			
Acteocina inculta	Mollusca : Gastropoda	14.0	6.40	24.17	7.00	0.02		
Capitella capitata Cmplx	Annelida : Polychaeta	15.0	6.17	32.72	1.91	0.05	0.47	
Euphilomedes carcharodonta	Arthropoda : Ostracoda	17.0	5.57	0.98	11.81	4.98	2.53	0.33
Tryonia imitator	Mollusca : Gastropoda	18.0	5.41	32.31				
Leptochelia dubia	Arthropoda : Tanaidacea	19.0	4.53	1.75	6.07	2.45	20.37	0.09
Spiophanes duplex	Annelida : Polychaeta	20.0	4.33	2.16	7.14	5.75	2.53	0.03
Streblospio benedicti	Annelida : Polychaeta	24.0	3.61	21.08	0.23			
Amphiodia urtica	Echinodermata : Ophiuroidea	25.0	3.60	0.92	1.11	11.64	3.77	0.01
Spiophanes norrisi	Annelida : Polychaeta	31.0	3.08	0.02	0.14	11.38	4.10	
Laphania boecki	Annelida : Polychaeta	33.0	2.75				35.03	
Spiophanes berkeleyorum	Annelida : Polychaeta	39.0	2.29		1.26	6.87	2.70	0.12
Monticellina siblina	Annelida : Polychaeta	40.0	2.21		2.46	5.70	0.33	
Amphiodia spp.	Echinodermata : Ophiuroidea	51.0	1.61	0.27	0.23	6.08	0.50	
Owenia collaris	Annelida : Polychaeta	53.0	1.57	0.44	0.13	5.98	0.33	
Photis californica	Arthropoda : Amphipoda	54.0	1.56		0.19	1.70	13.93	
Amphipholis pugetana	Echinodermata : Ophiuroidea	55.0	1.52			0.01	19.20	0.04
Paraprionospio alata	Annelida : Polychaeta	60.0	1.34		0.56	3.52	2.03	0.87

Table IV-5. Mean abundance of the ten most abundant species in each habitat.

Species	Higher Taxon	Overall Abundance Rank	Mean abundance (per 0.1 m^2)					
			Overall	Estuaries	Bays	Mainland Shelf	Channel Island Shelf	Slope and Basin
Spiophanes kimballi	Annelida : Polychaeta	64.0	1.29			3.88	1.87	1.22
Decamastus gracilis	Annelida : Polychaeta	65.0	1.28		0.01	2.38	8.87	0.06
Photis sp	Arthropoda : Amphipoda	69.0	1.20		0.07	0.87	12.20	0.04
Sabellaria nanella	Annelida : Polychaeta	73.0	1.14	0.06		4.75		
Mooreonuphis sp LA1	Annelida : Polychaeta	78.0	1.05				13.43	
Maldane sarsi	Annelida : Polychaeta	93.0	0.81		0.01	0.95	1.37	2.65
Ampelisca romigi	Arthropoda : Amphipoda	105.0	0.71			0.13	8.50	0.06
Dacrydium pacificum	Mollusca : Bivalvia	146.5	0.46					2.57
Macoma carlottensis	Mollusca : Bivalvia	203.0	0.31			0.16	0.23	1.38
Prionospio (Prionospio) ehlersi	Annelida : Polychaeta	249.0	0.24		0.02	0.02		1.23
Saxicavella pacifica	Mollusca : Bivalvia	272.5	0.21			0.18		0.96
Fauveliopsis glabra	Annelida : Polychaeta	277.0	0.21				0.03	1.14
Eclysippe trilobata	Annelida : Polychaeta	294.5	0.19			0.10		0.94
Yoldiella nana	Mollusca : Bivalvia	303.0	0.19					1.04

V. ASSESSMENT RESULTS

The purpose of this chapter is to assess the extent and magnitude of ecological habitat alteration in the Southern California Bight (SCB). Benthic condition is widely used as an indicator of alterations to biological responses due to disturbances of sediments, including those caused by chemical contamination. We evaluated benthic condition for the region at two temporal scales, first assessing the areas we sampled in 2008 for Bight'08 and then, where data were available, including comparable areas from Bight'08 and three previous regional monitoring efforts in 1994, 1998, and 2003 in a second assessment. Evaluations were conducted at three spatial scales: (a) the entire SCB, (b) geographic areas of interest (i.e., strata; Table II-4) individually, and (c) collectively as coastal or embayment habitats.

The extent of area with benthic assemblages showing clear evidence of disturbance was estimated in two steps. First, the condition of the benthic assemblage at each site was assessed using a measure of biointegrity. Next, individual site assessments in geographic areas of interest (strata) were combined to assess the extent and magnitude of alteration.

Benthic condition at a site was assessed on a four-category scale: Reference and Response Levels 1, 2, and 3 (Table II-3). A reference community is expected to occur at undisturbed reference sites. Response Level 1 (low disturbance) communities exhibit some indication of stress, but only within the measurement variability of reference condition. Response Level 2 (moderate disturbance) communities exhibit clear evidence of physical, chemical, other anthropogenic, or natural stress. Response Level 3 (high disturbance) communities exhibit a high magnitude of stress. Response Levels 2 and 3 are considered to be clear evidence of disturbed benthic communities in “poor condition” while Reference and Response Level 1 are not; they are considered in “good condition.” More details about our methods are provided in Chapter II.

Bight'08

We estimated that 6098 km^2 (99.7%) of the 6117 km^2 area assessed were in good condition in 2008 (Figure V-1). The balance 19 km^2 (0.3%) were in poor condition, with clear evidence of disturbance. Of the area in good condition, 5,548 km^2 (90.7%) were in Reference Condition and 551 km^2 (9.0%) were in Response Level 1 with low disturbance, which is not considered clear evidence of disturbance. Benthic condition at individual sampling sites is presented in Figure V-2 and Appendices D, E and F.

Of the habitats sampled in 2008, the island shelf stratum was in the best condition, with all sites in Reference condition and no evidence of disturbance (Table V-1; Figure V-3). All four coastal shelf strata were in good condition with all the sites assessed in Reference condition or low disturbance Response Level 1; no coastal sites were assessed in poor condition (Response Levels 2 or 3).

Of the strata sampled in 2008, embayments were in the worst condition both collectively (Figure V-3) and individually (Table V-1; Figure V-4). The most severely altered benthic communities (high disturbance Response Level 3) occurred only in these habitats. Collectively, 12.1% of the area sampled in the southern California embayments showed clear evidence of disturbance (Figure V-3). Larger proportions of estuaries were disturbed than marinas, ports, or other bays (Figure V-4), with 59.0% of estuarine area, 37.4% of marinas, 9.8% of ports, and 0.1% of other bays in poor condition. Benthic communities classified as high disturbance were present in estuaries (19.3% of the area) and marinas (0.3% of the area), but not in ports or other bays. In total, 15.6 km^2 out of a total of 128.7 km^2 of the bay and estuarine areas (12.1%) were in poor condition, with 2.1 km^2 (1.6%) classified as high disturbance.

Table V-1. Benthic condition of strata sampled in 2008 as the percentage of the area at each benthic community response level. Response levels 2 and 3 are considered to be clear evidence of disturbed benthic communities in "poor condition" while Reference and Response Level 1 are not. Detailed Condition Category definitions are provided in Table II-3.

Stratum	Area (km^2)	Response (Percent of area)			
		Reference	Low Disturbance Response Level 1	Moderate Disturbance Response Level 2	High Disturbance Response Level 3
Estuaries	11.9	9.8	31.1	39.7	19.3
Marinas	17.5	20.6	42.0	37.0	0.3
Ports	29.3	23.7	66.5	9.8	0.0
Bays	70.0	39.3	60.5	0.1	0.0
Inner shelf (10-30m)	1,171	70.0	30.0	0.0	0.0
Mid Shelf (31-120m)	2,019	96.9	3.1	0.0	0.0
Outer Shelf (121-200m)	605	92.9	7.1	0.0	0.0
Channel Island Shelf (5-200m)	2,193	100.0	0.0	0.0	0.0

Temporal Comparisons

The availability of data from four surveys over fifteen years provided an opportunity for evaluating temporal changes in some habitats. In addition to the Bight'08 samples collected in 2008, the Southern California Bight Pilot Project (SCBPP) sampled in 1994, Bight'98 sampled in 1998, and Bight'03 sampled in 2003. Strata sampled differed slightly between surveys (Table II-4) and temporal comparisons were restricted to areas that were sampled in multiple surveys. Only the inner and mid mainland shelf (to a depth of 120 m) was sampled during all four surveys (Table II-4). The outer mainland shelf, Channel Island shelf, and bays were sampled three times, while estuaries and coastal slopes were sampled twice. Similar RTS sampling designs were used for all four surveys.

The temporal comparisons indicated that the condition of benthos in habitats sampled during multiple surveys was not changing rapidly. The proportion of undisturbed area in good condition on the SCB inner and middle mainland shelf decreased from 98.5% in 1994 to 96.7% in 1998, returned to 98.6% in 2003, and increased to 100% in 2008 (Figure V-5); these changes were not statistically significant. The area in Reference condition decreased from 90.1% in 1994 to 82.6% in 1998 and 83.7% in 2003, and then increased to 87.4% in 2008. Most of this change from Reference was to Response Level 1, which increased from 8.4% in 1994 to 14.2%, 15.0%, and 12.6% in 1998, 2003, and 2008, respectively. Response Level 1 is not considered to be clear evidence of disturbed benthic communities.

Alteration at the most severe level, Response Level 3, was not observed anywhere on the coastal shelf during any of the regional surveys (Figure V-6). No distinct temporal trends were evident for shelf habitats that were sampled during multiple regional surveys.

No clear temporal trends were evident for embayment sites sampled in multiple regional surveys (Figure V-7), with substantial inter-survey variability in the extent of area in good condition. The extent of area in the four disturbance-related benthic response levels was also variable in all four embayment strata.

Analysis of assessment results at sampling sites from previous surveys that were revisited during Bight'08 (Table II-2) also showed no clear condition trends. Condition in shelf habitats was stable, with no Response Level changes at 55 of 59 revisited stations; two of the four stations that changed improved by one response level, while the other two declined by one response level (Table V-2). Changes in condition were more frequent and of larger magnitude in embayment habitats, but there was no evidence of consistent trends. Of 70 revisited stations, conditions changed by two response levels at 6 stations, and by one response level at 26 stations, but improvements and declines were of similar magnitude in both categories.

Table V-2. Assessment results for previously sampled stations revisited during Bight'08

Stratum	N	No Change	Improve		Decline	
			1 Response Level	> 1 Response Level	1 Response Level	> 1 Response Level
Estuaries	17	8	3	1	3	2
Marinas	20	11	4		5	
Ports	16	9	2	2	3	
Bays	17	10	2	1	4	
Embayments	**70**	**38**	**11**	**4**	**15**	**2**
Inner Shelf	14	11	2		1	
Mid Shelf	15	15				
Outer Shelf	15	14			1	
Channel Island Shelf	15	15				
Coastal	**59**	**55**	**2**	**0**	**2**	**0**

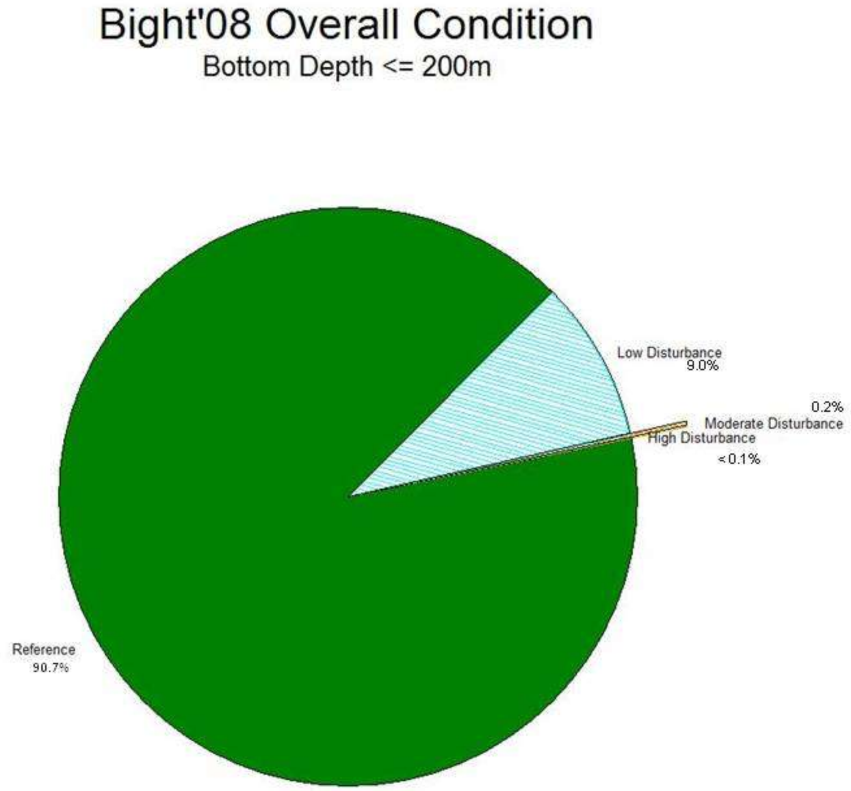


Figure V-1. Estimate of benthic condition for the area of the Southern California Bight sampled for Bight'08 in 2008. Benthic communities at response levels 2 and 3 (moderate and high disturbance) are considered to show clear evidence of disturbance. See Table II-3 for a detailed description of benthic condition categories.

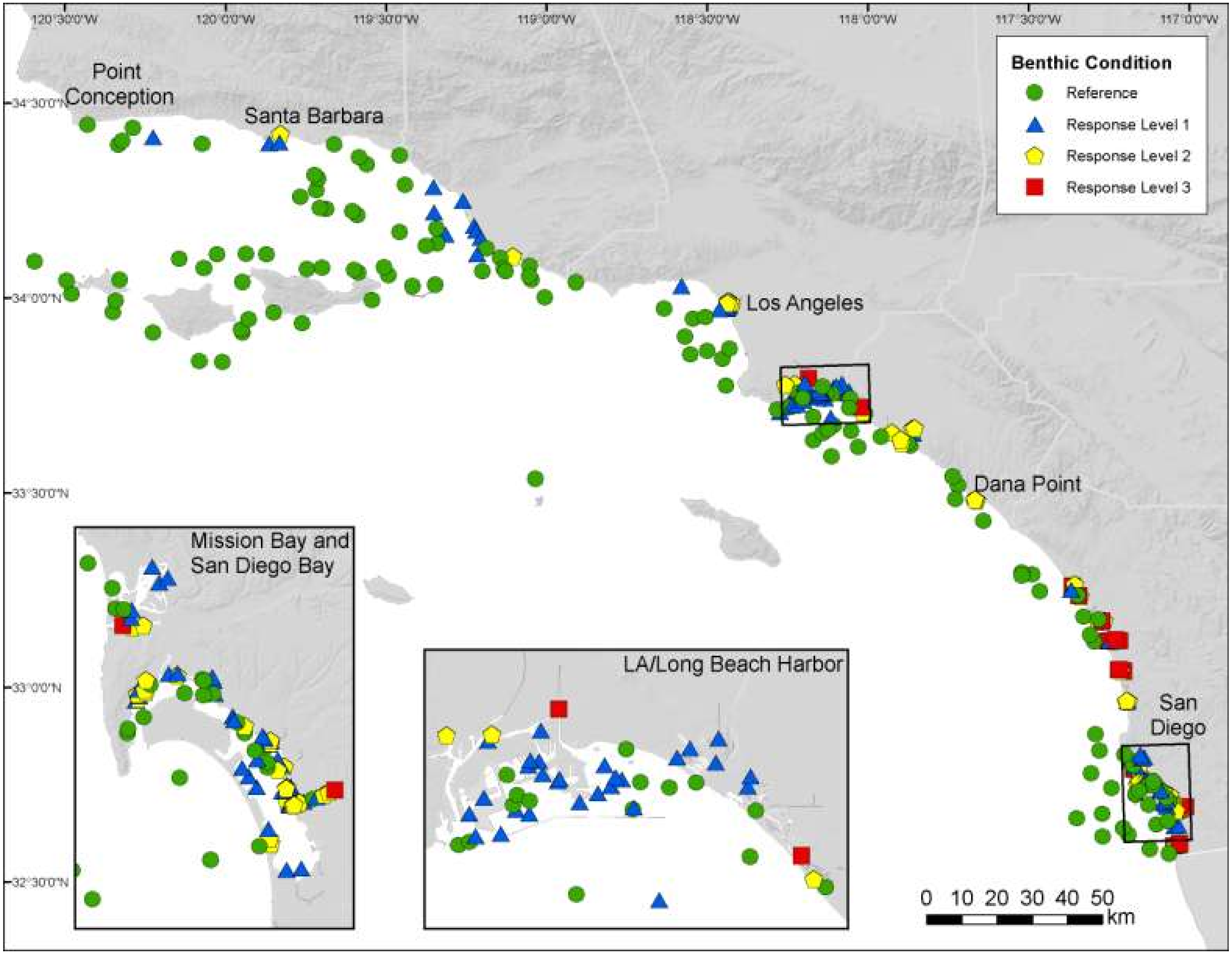


Figure V-2. Benthic condition at sites sampled in 2008 for Bight'08. See Table II-3 for a description of benthic condition categories and Appendix B for more detailed maps.

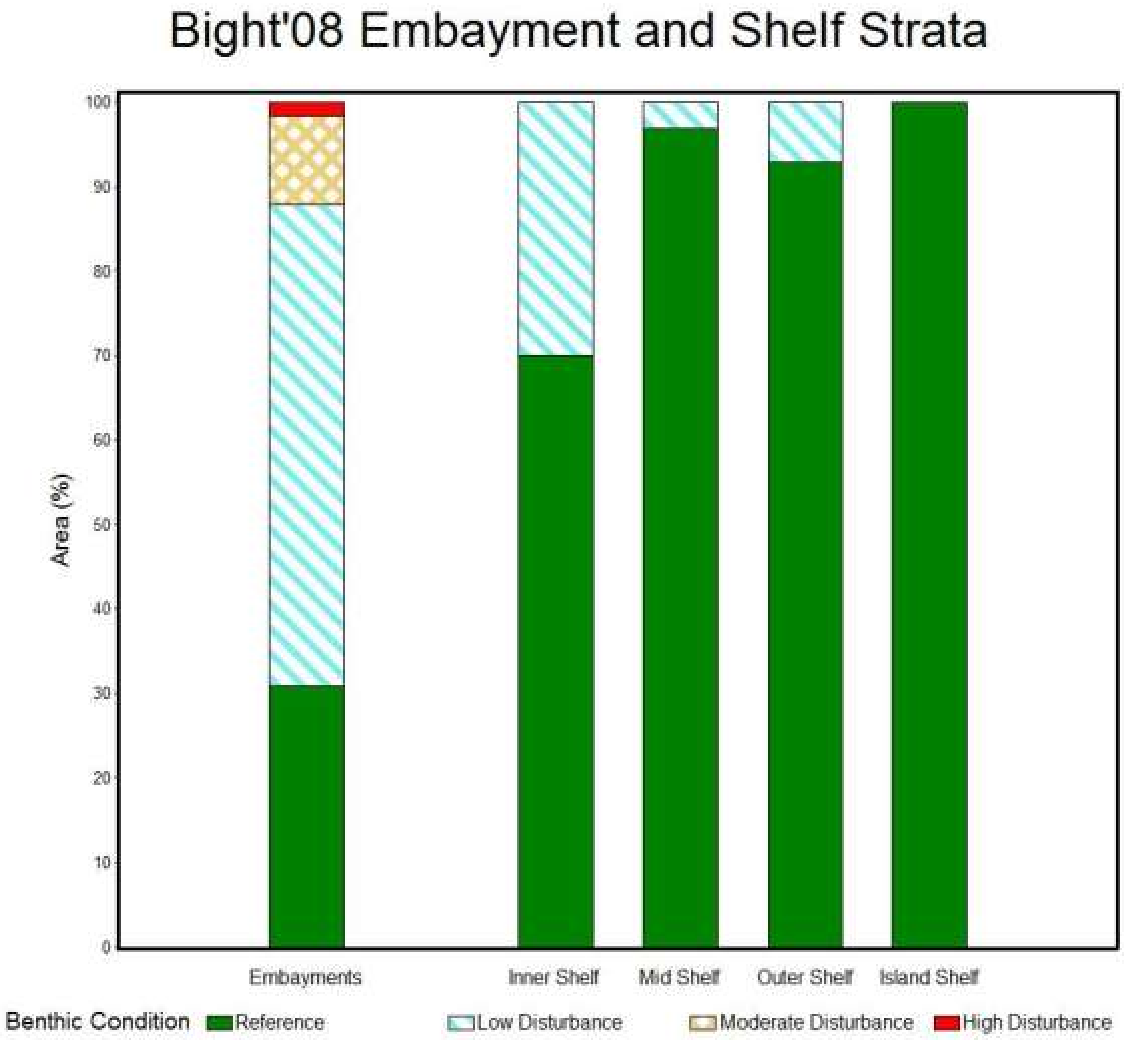


Figure V-3. Estimates of benthic condition for areas of interest (strata) sampled for Bight'08 in 2008. Benthic communities at response levels 2 and 3 (moderate and high disturbance) are considered to show clear evidence of disturbance. See Table II-3 for a detailed description of benthic condition categories.

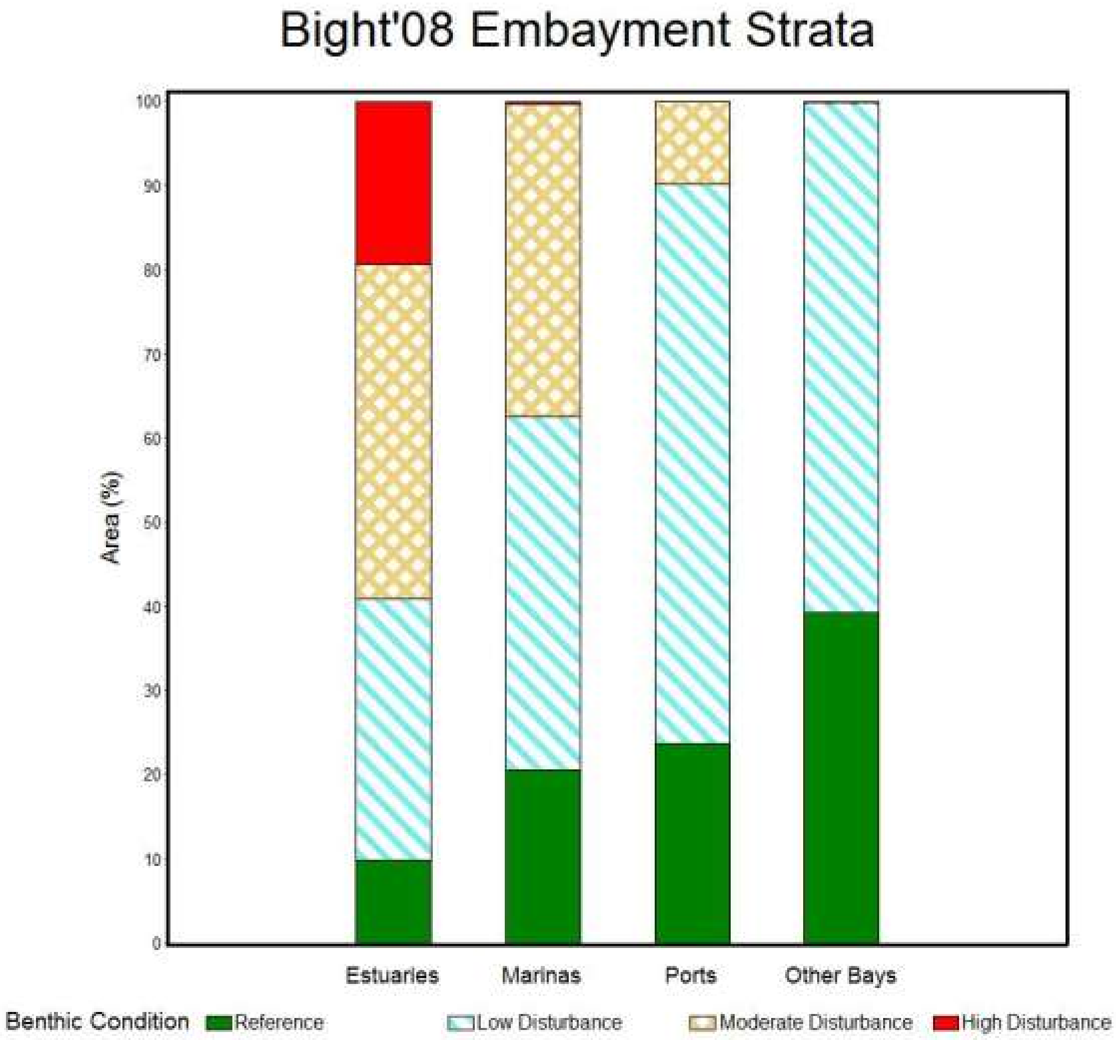


Figure V-4. Estimates of benthic condition for bay and estuary strata sampled for Bight'08 in 2008. Benthic communities at response levels 2 and 3 (moderate and high disturbance) are considered to show clear evidence of disturbance. See Table II-3 for a detailed description of benthic condition categories.

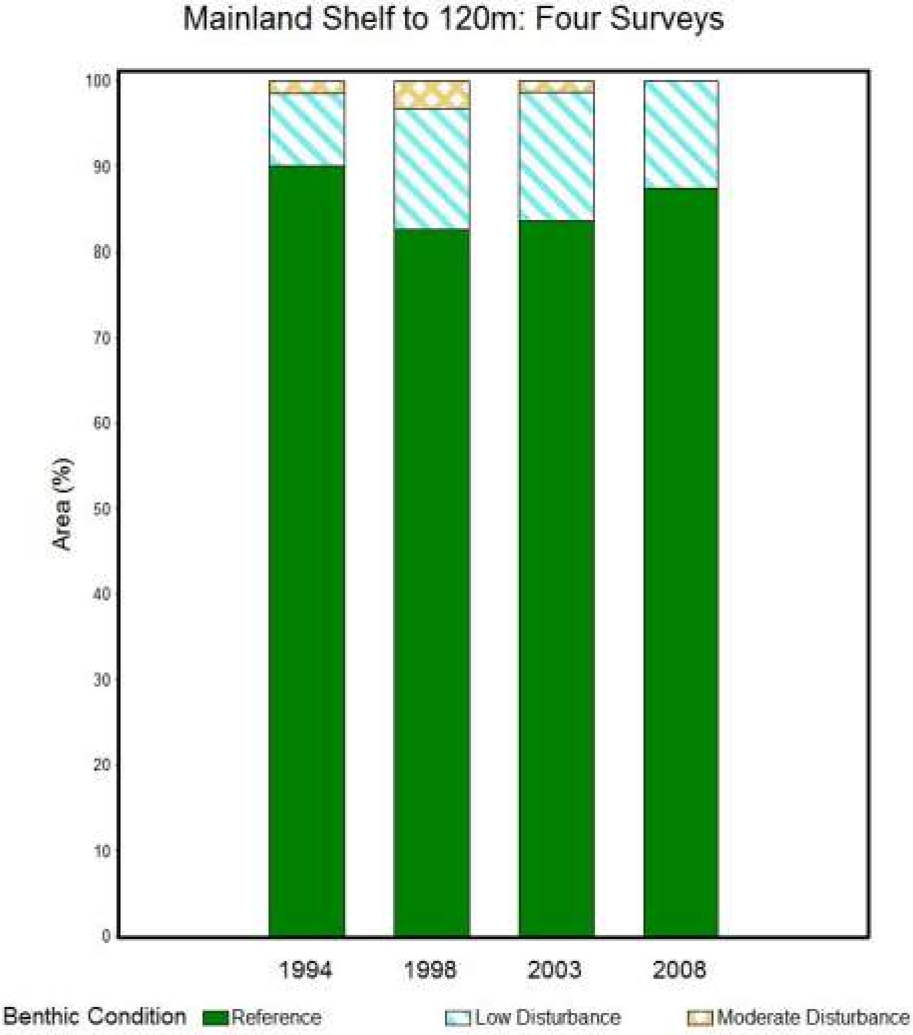


Figure V-5. Estimates of benthic condition for the mainland shelf area sampled in all four regional surveys. Benthic communities at response level 2 (moderate disturbance) are considered to show clear evidence of disturbance. See Table II-3 for a detailed description of benthic condition categories.

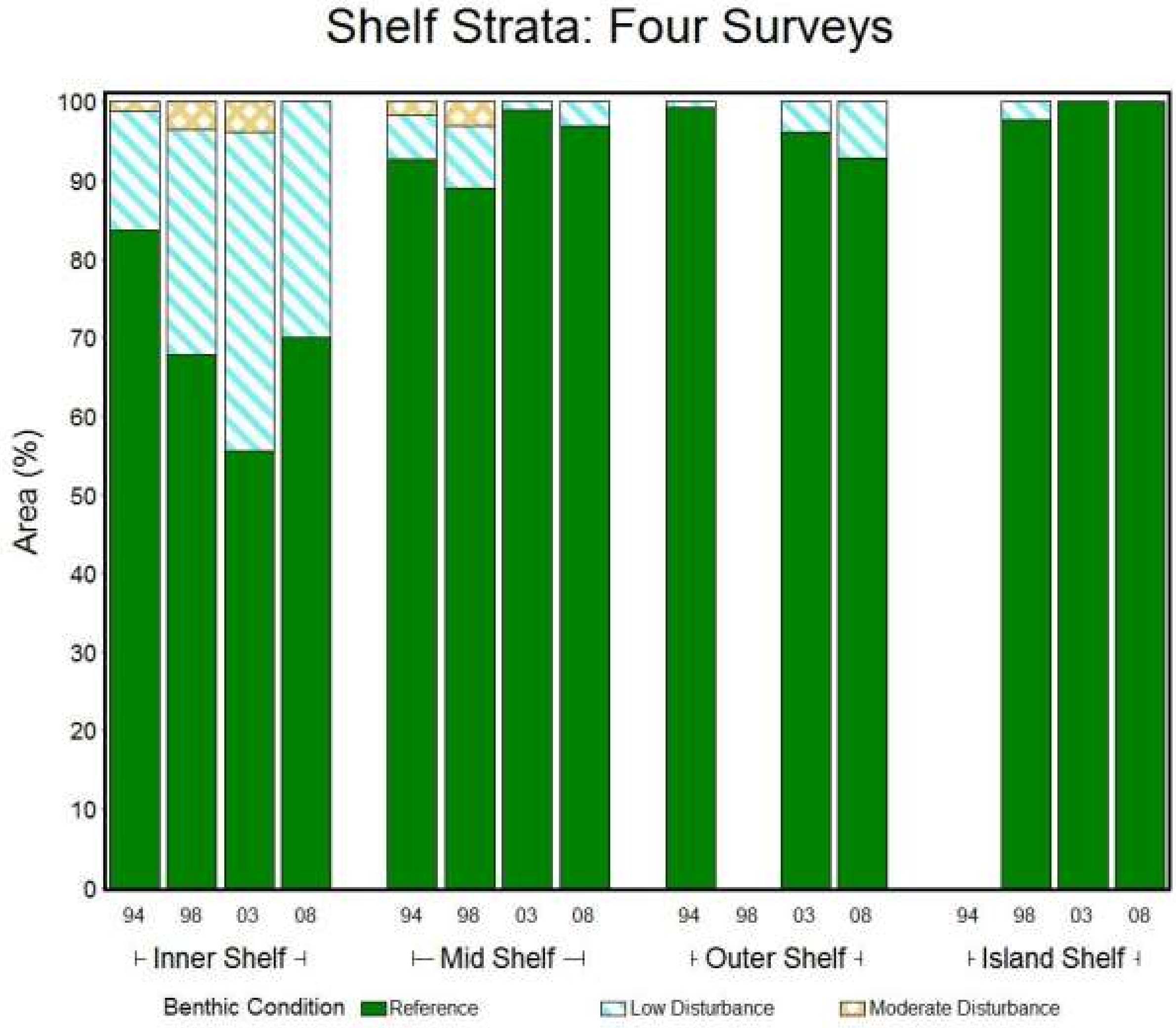


Figure V-6. Estimates of benthic condition for coastal areas of interest (strata) sampled in more than one regional survey. Benthic communities at response level 2 (moderate disturbance) are considered to show clear evidence of disturbance. See Table II-3 for a detailed description of benthic condition categories.

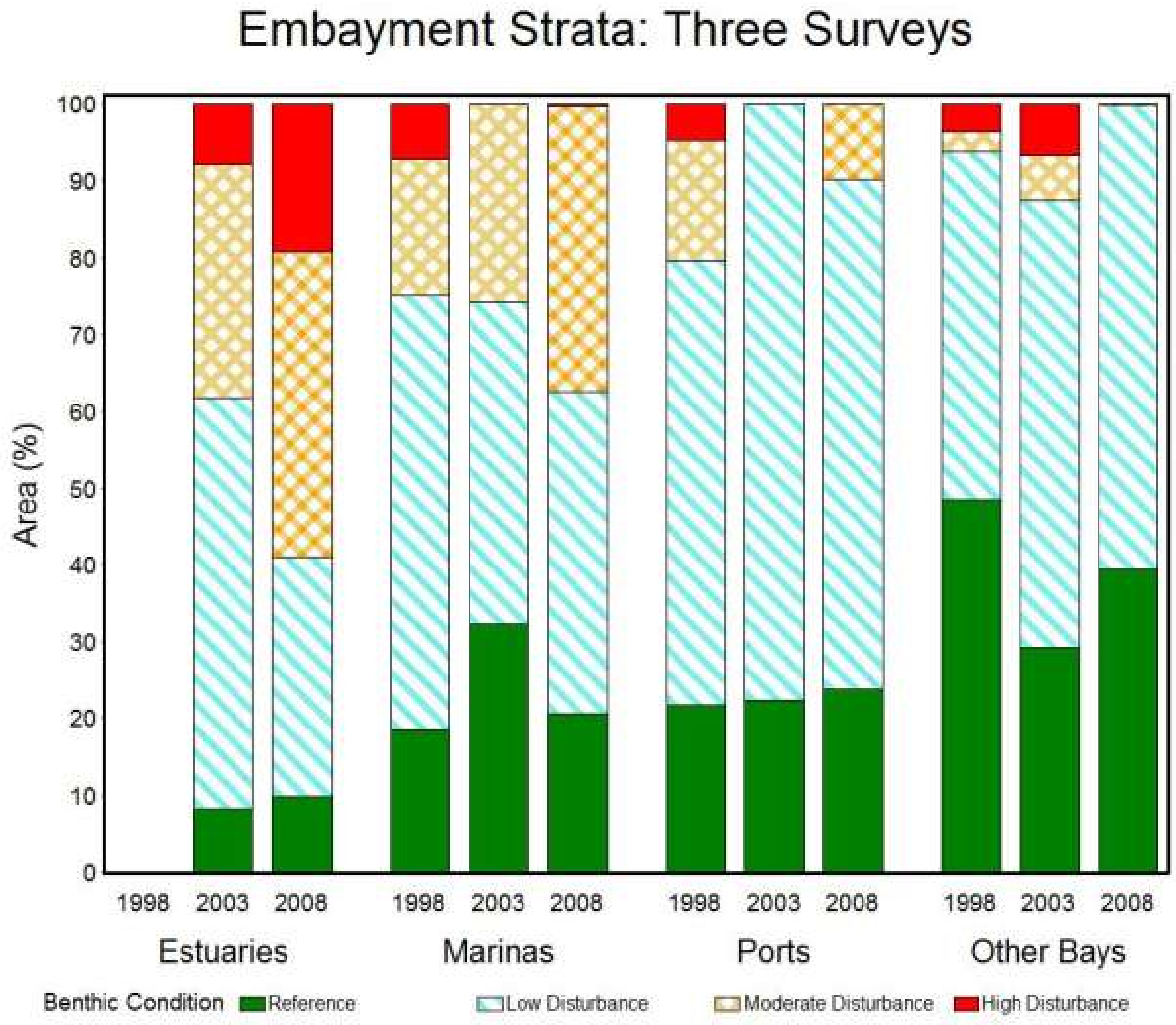


Figure V-7. Estimates of benthic condition for bay strata sampled during the 1998, 2003, and 2008 regional surveys. Benthic communities at response levels 2 and 3 (moderate and high disturbance) are considered to show clear evidence of disturbance. See Table II-3 for a detailed description of benthic condition categories.

VI. THE EFFECT OF GEAR SIZE ON BENTHIC ASSESSMENTS IN SOUTHERN CALIFORNIA EMBAYMENTS

This chapter documents a special study designed to improve cost-efficiencies in sampling and subsequent laboratory identification of embayment samples, the most laborious and expensive samples collected during Bight'08.

Introduction

Benthic grab sampling for benthic infaunal community analysis has been standardized since 1972 in the SCB (Word 1975, 1976a, 1976b). The standardized method has been used in SCB regional surveys dating back to 1976 (Word and Mearns 1979), the default sampling method in the SCB for every ongoing NPDES ocean monitoring program (e.g., City of Los Angeles Environmental Monitoring Division (2003), Aquatic Bioassay and Consulting Laboratories (2004), Orange County Sanitation District (2006), Sanitation Districts of Los Angeles County (2010)) and has been designated the sampling method of choice for implementing the State's regulatory policy on Sediment Quality Objectives (Ranasinghe *et al.* 2009). This standardized sampling consists of a weighted Van Veen grab with a surface area of 0.1 m^2. A standard Van Veen grab can weigh in excess of 50 pounds before deployment and additional weight or sample frames are often added at deep water sites or sites with sandy substrate. The use of tandem Van Veen grabs (twin deployment) is common. This heavy equipment is easily handled at offshore sites where large vessels use hydraulic winches to lower and raise the grab.

Van Veen grabs are also currently being used to sample shallow water embayments such as estuaries. The consistency with offshore sampling equipment is a function of historical data consistency for trend analysis, application of assessment tools calibrated and validated with samples taken with $0.1m^2$ Van Veen grabs, and lack of obvious choices for replacement sampling devices. However, the use of a $0.1m^2$ Van Veen grab in embayments is problematic and ultimately untenable. Unlike offshore, shallow water embayments cannot support large sampling vessels with hydraulic winches. Instead, small vessels with little draft and no hydraulics are necessary to access sample sites. As a result, Van Veen grabs are hand-hauled, which is exceedingly hard, back-breaking work. Ultimately, work crews run the risk of inefficient sampling, compromised samples, and declines in crew health and safety.

The goal of this special study was to assess differences in biological community composition and benthic condition estimates based solely on differences in sampled surface area. Sampled surface areas ranged from 0.01 to $0.1m^2$, to determine if smaller surface areas than the standard $0.1m^2$ could be used with comparable results in future embayment monitoring efforts.

Methods

Sediment samples for benthic macrofauna analysis were collected from 192 southern California embayment sites selected using a spatially random tessellation stratified (RTS) design. Samples were collected with a 0.1 m^2 Van Veen grab from July 2nd to September 28th and sieved through a 1 mm mesh screen. Only samples penetrating at least 5 cm into the sediment with no evidence of sediment disturbance (e.g., washout or slumping) were processed. Material retained on the screen was placed for at least 30 minutes in a relaxant solution of 1 kg $MgSO_4$ or 30 ml propylene phenoxytol per 20 L of seawater, and then preserved in 10% sodium borate buffered formalin.

Two $0.01m^2$ cores were removed from each sediment grab sample before sieving, and the three subsamples ($0.01m^2$ Core A, $0.01m^2$ Core B, and $0.08m^2$ Residue C; Figure VI-1) were processed independently. The data were analyzed as a comparison of $0.01m^2$ (Core A), $0.02m^2$ (combining Core A+Core B data), $0.08m^2$ (Residue C), and $0.1m^2$ (combining Core A, Core B, and Residue C data; Figure VI-1) surface areas. The $0.1m^2$ samples are the standard sample size in southern California and thresholds and criteria used to assess benthic condition are based on biodiversity, species composition and species abundances in these samples. Community measures and benthic indices were calculated for the $0.01m^2$, $0.02m^2$, $0.08m^2$, and $0.10m^2$ surface area samples. Species abundances were standardized to $0.1m^2$ for all subsamples, but no standardization of biodiversity measures, including numbers of species, was possible. The number of individuals is linearly related to sample area and can be multiplicatively adjusted, whereas the relationship between number of species and sample area is nonlinear (Preston 1948, Connor and McCoy 1979, Rey *et al.* 1982) and varies among habitats; thus species richness cannot be normalized as easily as abundance.

The data were analyzed in four ways. First, the consistency of the fauna in the $0.01m^2$ A and B cores was evaluated by linear regression analysis of abundances and taxon richness. If relationships are weak and variability high, $0.01m^2$ samples likely are too inconsistent to adequately represent each other, and by extrapolation, the $0.1m^2$ grab sample in its entirety.

Second, relationships between abundances and taxon richness among the four test gear area sizes were evaluated by linear regression analysis. Traditional entire $0.1m^2$ sample abundance and taxon richness were treated as independent variables and the three smaller test sample areas ($0.01m^2$, $0.02m^2$, and $0.08m^2$) were treated as dependent variables.

The third approach evaluated the effect of gear area on the Benthic Line of Evidence used to assess benthic community condition for California's Sediment Quality Objectives (Ranasinghe *et al.* 2009) and the four benthic indices that contribute to it: the Benthic Response Index (BRI; Smith *et al.* (2001), Smith *et al.* (Smith *et al.* 2003)), the River Invertebrate Prediction and Classification System (RIVPACS; Wright *et al.* (1993), Van Sickle *et al.* (2006)), the Relative Benthic Index (RBI; Hunt *et al.* (2001)), and the Index of Biotic Integrity (IBI; Thompson and Lowe (2004)). The BRI is a measure of the abundance-weighted pollution tolerance of species present in a sample, while RIVPACS is the ratio of observed species to those expected in undisturbed reference samples in similar habitats. The RBI and IBI are multi-metric indices based on community parameters, such as abundance, number of species, and number of individuals in selected indicator taxonomic groups. Ranasinghe *et al.* (2009) describe calculation of these indices. Application of the indices was limited to habitats for which they were previously calibrated; all four indices were previously calibrated and validated for Southern California marine bays (Ranasinghe *et al.* 2009).

The effects of gear on the indices were evaluated in two ways. The first was to assess changes in magnitude of the index value. The second was to determine how any changes in index values affected the assessment of condition within the context of California's Sediment Quality Objectives, which classify sediments into four condition assessment categories: (1)

Reference - a community that would occur at a reference site for that habitat; (2) Low disturbance - a community that exhibits some indication of stress, but within measurement variability of reference condition; (3) Moderate disturbance - a community that exhibits evidence of physical, chemical, natural or anthropogenic stress; and (4) High disturbance - a community exhibiting a high magnitude of stress. Samples in categories 3 and 4 are considered to be in poor condition, while categories 1 and 2 are considered to be in good condition.

Finally, cost effectiveness was evaluated by calculating sorting and taxonomy (identification and enumeration) cost factors for the different sample sizes and comparing them to community measure differences and variability. Sorting and taxonomy cost factors were expressed as 100 for the traditional entire $0.1 m^2$ sample; for the smaller test gear sizes cost factors were expressed as percentages relative to costs for the traditional gear.

Results

Linear regression indicated highly significant ($p < 0.0001$) relationships for total abundance and taxon richness between paired $0.01 m^2$ cores (Figure VI-2) for the 192 embayment grab samples. The regression relationship was stronger for total abundance ($r^2 = 0.78$) than taxon richness ($r^2 = 0.64$). Despite the stronger relationship denoted by the larger coefficient of determination, much larger outlier values were observed for abundance compared to taxon richness.

For abundance standardized to $0.1 m^2$, the larger $0.08 m^2$ samples exhibited stronger relationships with the standard $0.1 m^2$ gear than the smaller $0.02 m^2$ and $0.01 m^2$ samples (Figure VI-3) with coefficients of determination of 0.81, 0.65, and 0.72, respectively. For the three test sample sizes, regression lines (Figure VI-3) and observed values (Table VI-1) indicated approximately equal standardized abundances with the standard $0.1 m^2$ samples.

Table VI-1. Means and standard errors for abundance, taxon richness, and four California Sediment Quality Objectives (SQO) measures of benthic community condition for four sampling gear area sizes. SQO assessments are based on $0.10 m^2$ samples.

Measure	Gear Area			
	$0.01 m^2$	$0.02 m^2$	$0.08 m^2$	$0.10 m^2$
Abundance	540.8	657.7	669.9	664.0
(adjusted to $0.1 m^2$)	± 75.6	± 170.1	± 57.0	± 68.1
Number of taxa	12.2	17.9	37.8	41.8
	± 0.57	± 0.76	± 1.66	± 1.76
SQO Benthic Line of Evidence (BLOE)	2.82	2.47	2.01	1.92
	± 0.072	± 0.074	± 0.066	± 0.063
Benthic Response Index	50.0	47.3	45.1	44.0
(BRI)	± 1.95	± 1.82	± 1.65	± 1.60
Relative Benthic Index	0.09	0.13	0.27	0.30
(RBI)	± 0.009	± 0.010	± 0.016	± 0.016
Index of Biotic Integrity	1.62	1.21	0.73	0.73
(IBI)	± 0.080	± 0.073	± 0.054	± 0.050

Patterns of relationship strength were similar for taxon richness (Figure VI-4) and standardized abundance, with coefficients of determination of 0.98, 0.65, and 0.53 between the $0.08 m^2$, $0.02 m^2$, and $0.01 m^2$ samples and the standard $0.10 m^2$ samples. However, taxon richness approached equality with the standard $0.10 m^2$ samples only for the large $0.08 m^2$ samples. The taxon richness linear regression slopes for the $0.01 m^2$ and $0.02 m^2$ samples were

0.24 and 0.35, versus 0.94 for the 0.08 m^2 samples. Taxon richness for the smaller 0.01 m^2 and 0.02 m^2 samples were less than for the larger 0.08 m^2 and 0.10 m^2 samples by factors of 2-4 (Table VI-1).

Assessments of benthic condition that calculated the California Sediment Quality Objectives Benthic Line of Evidence (BLOE) for the four sample sizes also differed substantially between the largest and smallest (0.01 m^2) sample sizes. The extent of SCB area considered disrupted monotonically increased from 12% of embayments using 0.10 m^2 samples to 56% of SCB embayments using 0.01 m^2 samples (Figure VI-5, Table VI-1). Of the four benthic indices that contribute to the BLOE, the Benthic Response Index (BRI) was relatively insensitive to gear size (Figure VI-6, Table VI-1), while the Relative Benthic Index (RBI) and Index of Biotic Integrity (IBI) evaluated smaller samples in poorer condition than large samples.

The cost factor for taxonomy (identification and enumeration) increased by a factor of five from 0.01 m^2 to 0.10 m^2 samples, while the sorting cost factor increased by a factor of 2.5 (Table VI-2). These increases in effort can be directly attributable to increases in abundance and taxon richness by factors of 12.3 and 3.4, respectively (Table VI-2).

Table VI-2. Average community measures and cost factors for four sampling gear area sizes. SQO assessments are based on 0.10 m^2 samples, which were assigned cost factors of 100.

Measure	Gear Area			
	0.01 m^2	**0.02 m^2**	**0.08 m^2**	**0.10 m^2**
Abundance (unadjusted)	54.0	131.5	536.0	664.0
Number of taxa	12.2	17.9	37.8	41.8
SQO Benthic Line of Evidence (BLOE)	2.82	2.47	2.01	1.92
Sorting cost factor	40	45	85	100
Taxonomy cost factor	20	40	60	100

Discussion

Our findings are consistent with previous studies examining relationships between sample surface area and the number of organisms and biodiversity that are captured. The number of individuals was linearly related to sample area and can be multiplicatively adjusted, whereas the relationship between taxon richness and sample area was nonlinear (Preston 1948, Connor and McCoy 1979, Rey *et al.* 1982, Hammerstrom *et al.* In Press) and varies among habitats; thus taxon richness cannot be normalized as easily as abundance. In several earlier studies, the dominant species were relatively unaffected by sample surface area and sieve size (Ferraro and Cole 2004) and the clustering of samples in ordination space was affected only to a small degree by sample area or sieve size (James *et al.* 1995, Ferraro *et al.* 2006, Hammerstrom *et al.* In Press). Hammerstrom *et al.* (In Press) had similar findings, but our study focused on a single embayment type (saline bays and estuaries) with approximately 10 times as many samples.

Laboratory cost savings based on reduced sample surface area came at the expense of large increases in the estimated extent of biological community disturbance. Traditional methods identified 12% of the SCB embayments as disturbed compared to the least expensive methods that estimated over 50% of SCB as disturbed. This large estimated difference was a function of the four different indices combined in the Sediment Quality Objectives benthic line of evidence. The BRI was least affected because it is based primarily on species composition, which was only marginally altered by sample area. In contrast, the RBI was most affected because it is based primarily on overall numbers of species and numbers of species within selected indicator taxonomic groupings, which were most altered by sample surface area.

Ultimately, none of the tested sample areas were clearly preferable to the existing standard method of 0.1 m^2. While the 0.08 m^2 came closest to the 0.1m^2 results, the cost savings were minimal and substantial negative bias in taxon richness and areal extent of disturbed benthic community condition still existed. However, three options remain that could be explored for identifying a preferred alternative sampling method. The first option would be to constrain the multiple indices used to judge community disturbance and focus only on the indices, such as the BRI, that were insensitive to differences in sampling area. However, the superior performance of index combinations over the performance of any one index was clearly evident during the development of the State's Sediment Quality Objectives (Ranasinghe *et al.* 2009). This is likely because species diversity plays an important role in determining community health. Therefore, a second option may be to identify alternative thresholds for the biodiversity-focused indices (i.e., RBI) that are specific for different sampling areas. The third option is to explore new indices. One such alternative index is the AMBI (AZTI Marine Biology Index) and its multivariate companion M-AMBI. The AMBI is a biointegrity tool based on species composition that is used extensively in Europe (Borja *et al.* 2000, Borja *et al.* 2003, Muxika *et al.* 2005). The M-AMBI adds a biodiversity assessment component to species composition assessment by the AMBI (Muxika *et al.* 2007). Regardless of which option(s) is chosen, seeking more cost-effective methods for collecting representative samples in southern California embayments is important for the success of future estuarine monitoring and assessment.

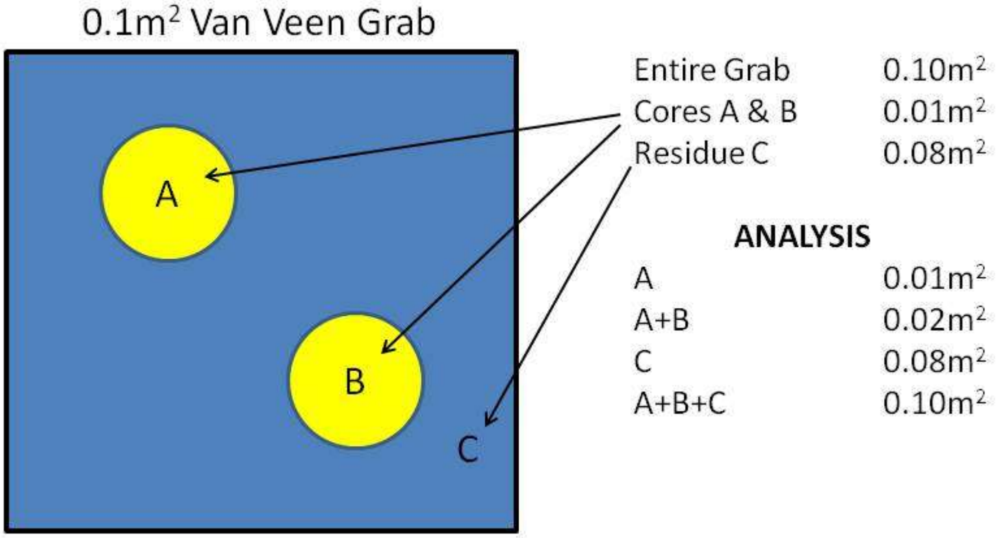
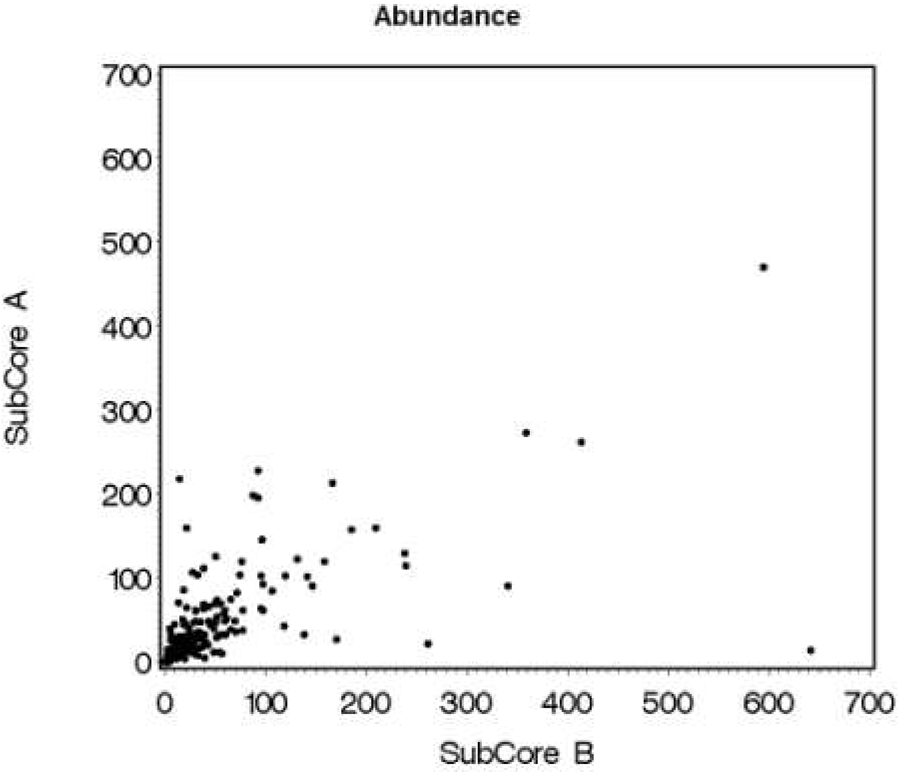


Figure VI-1. Grab sample schematic showing 0.1m^2 cores A and B and 0.08m^2 residue C and combination of abundance data into 0.01m^2, 0.02m^2, 0.08m^2, and 1.00m^2 sub samples for data analysis.



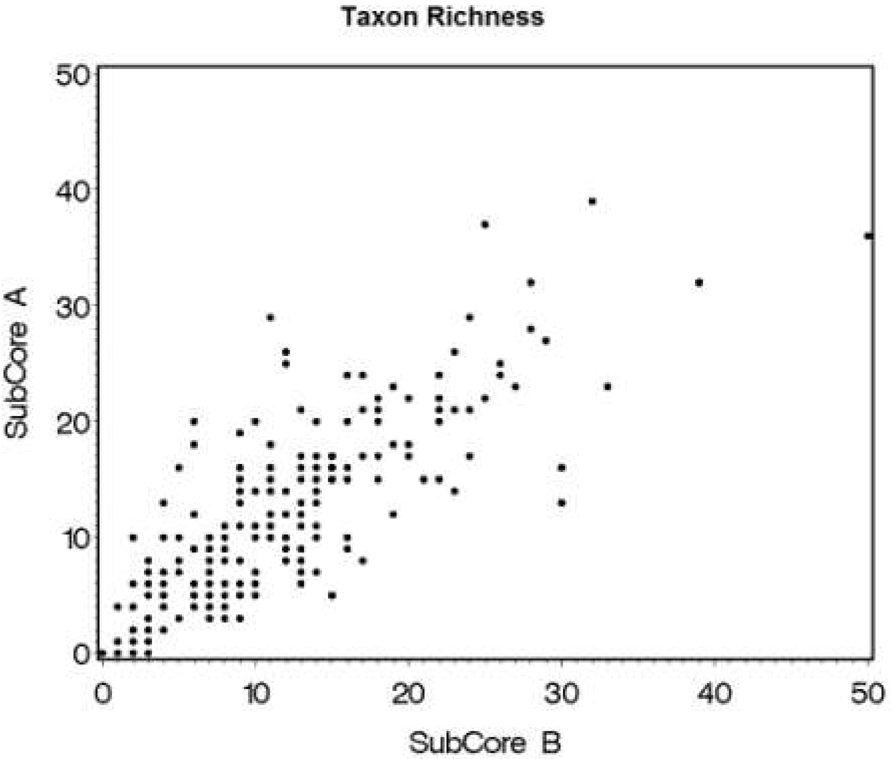


Figure VI-2. Relationships in standardized total abundance (top) and taxon richness (bottom) between 0.1m^2 Cores A and B in 192 southern California embayment samples. The coefficient of determination (r^2) is 0.78 for abundance and 0.64 for taxon richness.

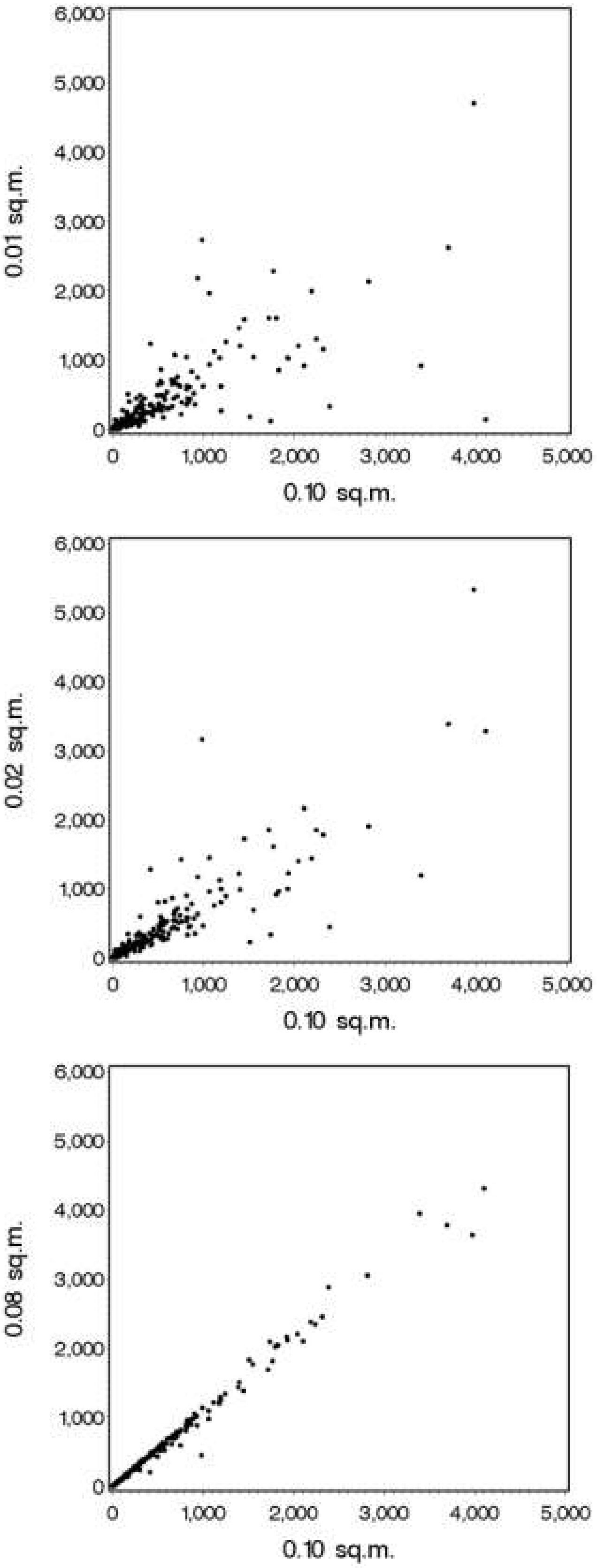


Figure VI-3. Relationships in standardized total abundance between gear of area 0.01m^2 (top), 0.02m^2 (center), and 0.08m^2 (bottom) and standard 0.10m^2 gear. Coefficients of determination (r^2) are 0.72, 0.65, and 0.81 for the 0.01m^2, 0.02m^2, and 0.08m^2 gear, respectively.

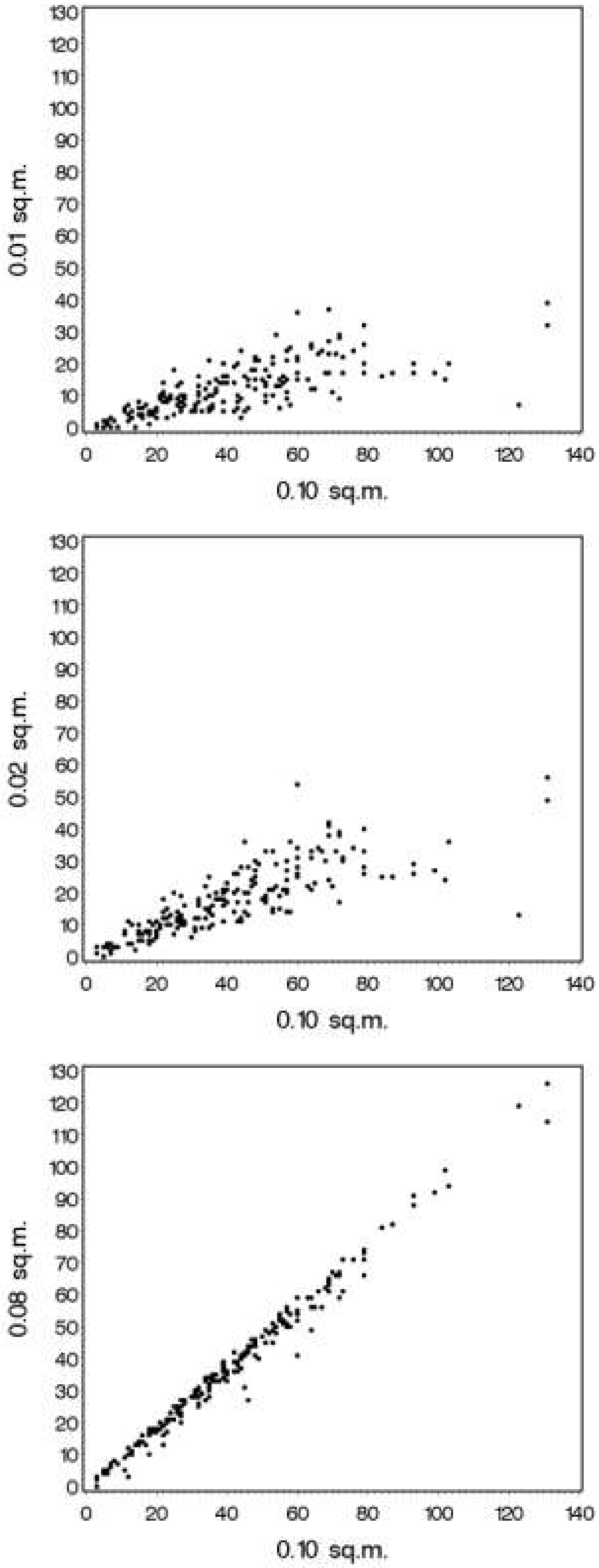


Figure VI-4. Relationships in taxon richness between gear of area $0.01m^2$ (top), $0.02m^2$ (center), and $0.08m^2$ (bottom) and standard $0.10m^2$ gear. Coefficients of determination (r^2) are 0.53, 0.65, and 0.98 for the $0.01m^2$, $0.02m^2$, and $0.08m^2$ gear, respectively.

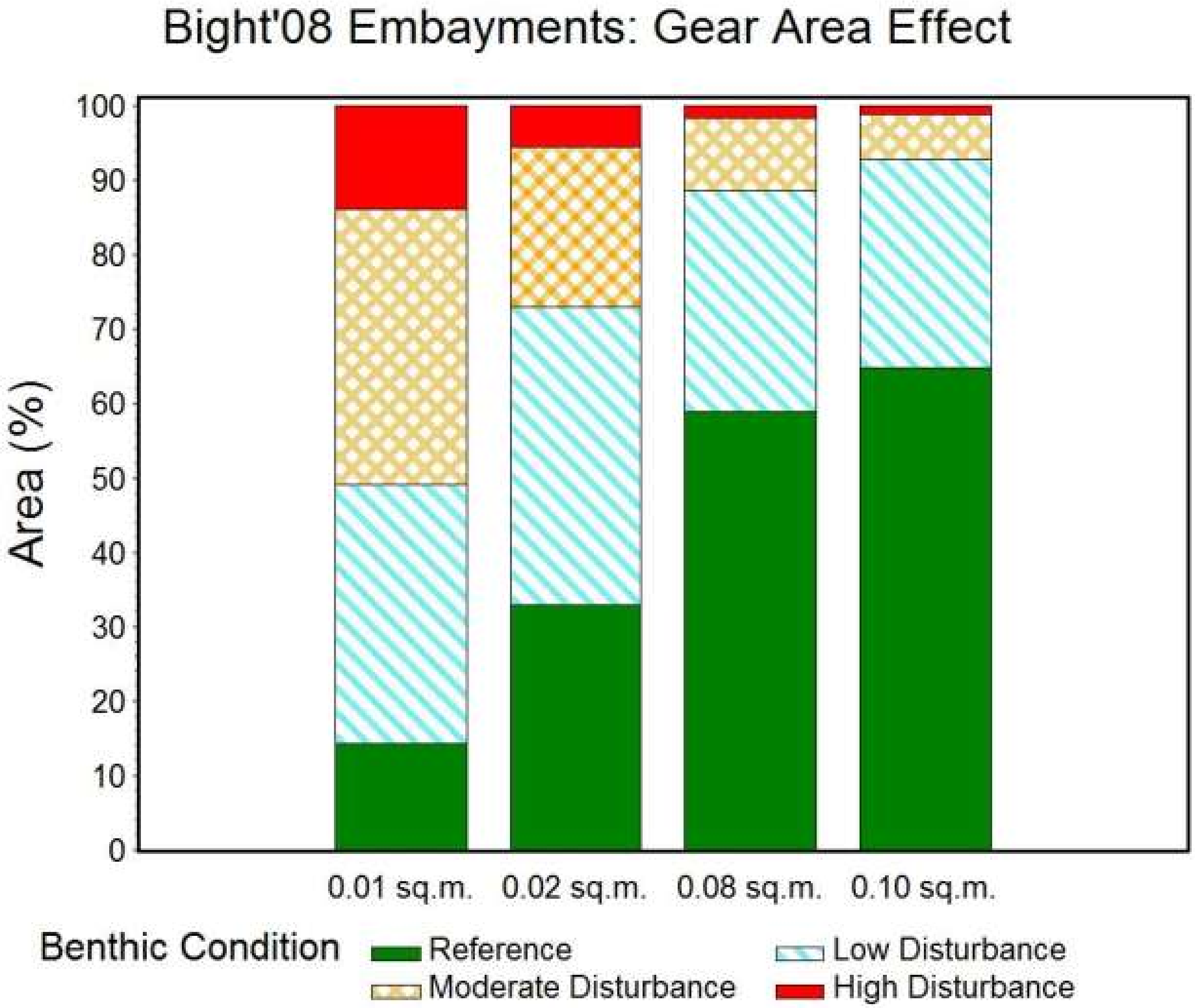


Figure VI-5. Assessment results for embayment areas sampled in Bight'08 by applying California Sediment Quality Objectives methodology to 0.01 m^2, 0.02 m^2, 0.08 m^2, and 0.10 m^2 samples. Standard SQO assessments are based on 0.10 m^2 samples. They are based on calculating the median of four benthic indices.

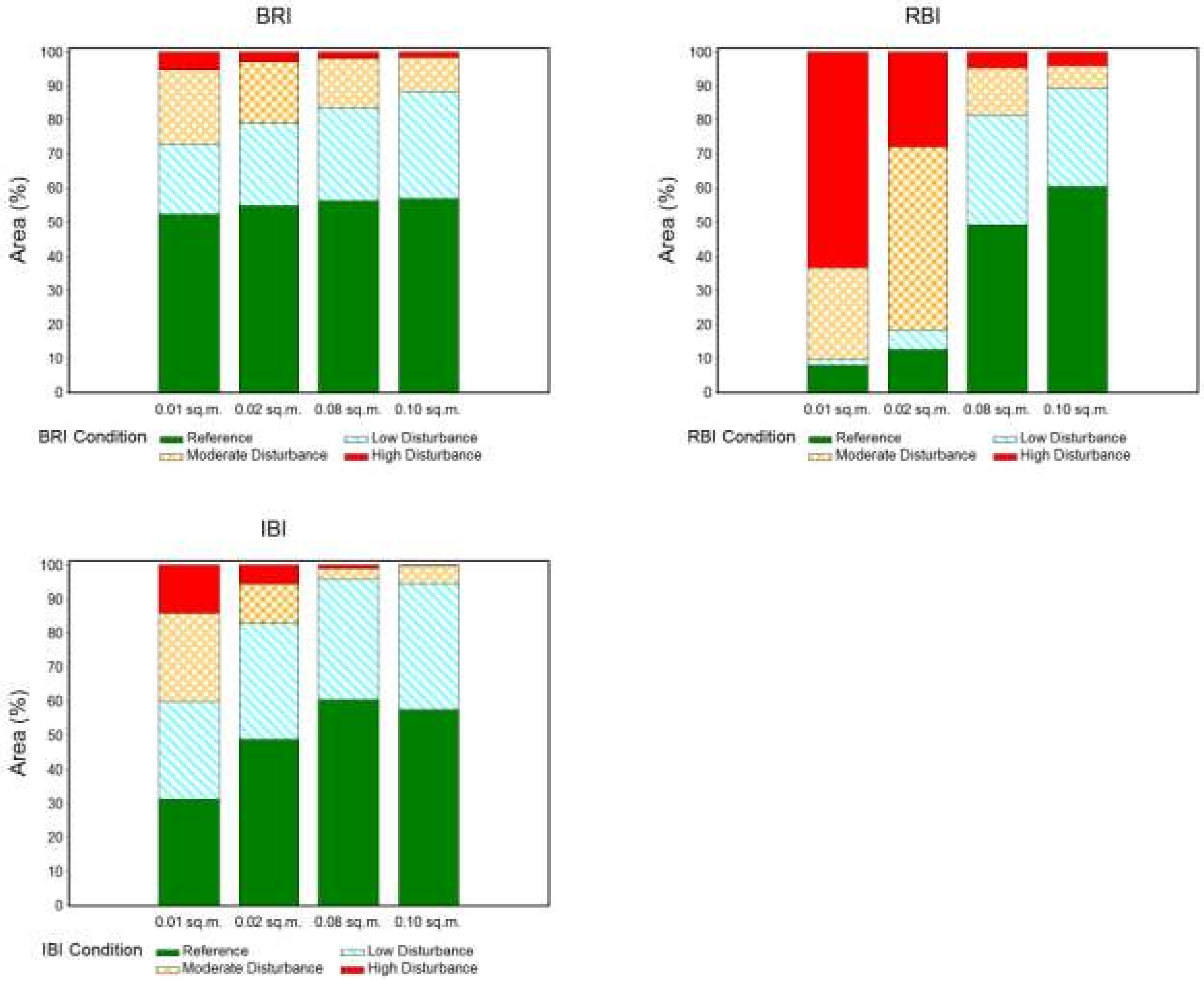


Figure VI-6. Assessment results for embayment areas sampled in Bight'08 for the benthic index components (Benthic Response Index (BRI), top left; Relative Benthic Index (RBI), top right; and Index of Biotic Integrity (IBI), bottom left) of California's sediment quality objectives using 0.01 m^2, 0.02 m^2, 0.08 m^2, and 0.10 m^2 samples.

VII. DISCUSSION

While benthos appeared healthy throughout the SCB in 2008, not all habitats were in the same condition. More than 99% of the SCB supported benthic macrofaunal communities in good condition. None of the benthos sampled on the Channel Island shelf, or the inner, middle and outer mainland shelf were considered to be in poor condition. However, over half the benthos in estuaries, and more than a third of the benthos in marinas, were clearly disturbed. Other investigators have observed the impact to benthos in marinas of the SCB. Fairey *et al*. (1996) found that most of the degraded benthic sites in San Diego Bay were in or near shipyards and marinas. Anderson *et al*. (2001) determined that the Dominguez Channel/Consolidated Slip, which contains a marina and receives discharges from an urban watershed, had the most degraded benthos in Los Angeles/Long Beach Harbor. Similarly, stations in the back basins of Marina Del Rey had benthos in poor condition (Aquatic Bioassay and Consulting Laboratories 2004). In contrast to marinas, very little study of benthic condition has been attempted in estuaries of the SCB. Bight'03 and Bight'08 determined that estuaries in the SCB were 7 to 14 times more likely to have impacted benthos relative to the rest of the SCB, and Bight'03 determined that the benthos in the most urban estuaries (e.g., LA estuaries) were 25% more likely to be in poor condition than other, less urban, estuaries of the SCB.

Marinas and estuaries may have relatively poor benthic condition because these habitats are receptors of many sources of potential pollutants. Estuaries receive inputs from agricultural, construction, and urban upstream activities. Bight-wide, pollutant loadings from agricultural and urban watersheds rival pollutant loadings from more traditional sources such as large and small POTWs (Ackerman and Schiff 2003, Schiff *et al.* 2003). Unlike POTWs, however, watershed discharges are untreated and estuaries serve as sinks where these watersheds meet the ocean. Marinas receive pollutant inputs from recreational boating activities, which can contribute significant quantities of copper from antifouling bottom paints and petroleum hydrocarbons from fuels (Schiff *et al.* 2004). Relatively high concentrations of metals and trace organic pollutants have been measured in sediments from SCB marinas and estuaries previously (Fairey *et al.* 1996, Anderson *et al.* 1998). Schiff *et al.* (2006) found that estuaries and marinas of the SCB had the greatest extent of chemical contamination and were predisposed to accumulating sediment contaminants relative to other habitats of the SCB in 2003. Bay *et al.* (2005) also determined that marinas and estuaries had the greatest frequency of sediment toxicity relative to other habitats in the SCB in 2003. Estuarine fauna are also subject to substantial natural seasonal stress due to the Mediterranean climate of southern California. Rainfall is heavy, but restricted to a few months of the year. Massive freshwater flows in fall and winter result in osmotic stress as organisms struggle to prevent electrolyte loss and dilution, and physical stress as strong currents scour bottom sediments. Thus, it was not surprising that estuaries and marinas were determined to be in poorer benthic condition than ports, other industrialized waterways, and the coastal shelf.

The precision and accuracy of benthic condition assessment is a function of the assessment tools used. Assessment tools help to condense the tremendous amount of biological information in a sample into a single number that is easier to understand and communicate to others. For example, an average sample from the mainland shelf of the SCB may contain thousands of individuals and hundreds of species per square meter. Two assessment tools were used in this study; the BRI for mainland continental shelf and upper continental slope habitats and the benthic line of evidence (BLOE) developed for the State of California's Sediment Quality Objectives program for embayment habitats. Because embayments had rarely been assessed previously, the BLOE was specifically developed for Bight'03 (Ranasinghe *et al.* 2009). The BLOE is a combination of multivariate and multi-metric biointegrity indices that has limited applicability in certain situations. For example, it was not developed for brackish (<27 psu) water estuaries and lagoons. Several of the lagoons sampled in the SCB during the summers of 2003 and 2008 were considered brackish and, thus, could not be evaluated.

The BRI used to assess benthic condition on the mainland shelf and upper slope also has its limitations. The BRI is a multivariate-based assessment tool that was calibrated for depths from 10-324 m. Validation analyses showed that the BRI was most accurate between 31-200 m, which includes habitats on the middle and outer continental shelf. There was no calibration of the BRI for sites greater than 324 m depth and only limited calibration from 200 m to 324 m, so the BRI was not used to assess the SCB continental slope and basins. This remains a point of interest because Schiff *et al.* (2006, 2011) indicated that the SCB continental slope and basins are habitats that appear to accumulate sediment contaminants. Despite attempts to improve its performance in depths less than 30m, the BRI remains less accurate in evaluating samples from the inner shelf, presumably because there was less of a pollution gradient available for calibration.

Despite their success in assessing benthic condition, neither the BRI nor BLOE can discriminate the individual stressor(s) responsible for poor benthic condition. In addition, neither the BRI nor the BLOE can distinguish between anthropogenic (e.g., chemical stress) and natural (e.g., salinity or storm-related) impacts. Ultimately, the goal of any assessment would be to measure and designate the likely stressor(s) of benthic condition.

It appears that the SCB mainland shelf is not changing rapidly. Results from the current study in 2008 were similar to the estimates from regional studies in 1994 (Bergen *et al.* 1998, 2000), 1998 (Ranasinghe *et al.* 2003a), and 2003 (Ranasinghe *et al.* 2007). The area of the coastal shelf in poor benthic condition remained between 1.4 and 3.3% between 1994 and 2003 and reduced to zero in 2008. This temporal assessment of benthic condition is limited, however, to the inner and middle coastal shelf strata that were sampled in all three surveys. Trend information from other habitats of interest (i.e., embayments) cannot be assessed at this time. There were three mainland shelf areas that had the most sites deviating from good benthic condition in 1994, 1998, and 2003; these included sites located on the Palos Verdes Shelf, Santa Monica Bay, and the Eastern Santa Barbara Channel. In the present study, none of the sites in these areas were in poor benthic condition.

The Bight regional monitoring program series are not presently designed to detect temporal trends. One potential limitation to assessing temporal trends is consistency in taxonomy among surveys, but this problem has been overcome and the Bight program is now the model of consistency and quality nationally (Ranasinghe *et al.* 2003b). A second weakness to trend detection is spatial. The only strata consistently sampled in the surveys from 1994, 1998, 2003 and 2008 have been the inner and middle shelf. A third limitation is the magnitude of change that the current design can effectively detect; 95% confidence intervals about areal estimates for any single stratum is approximately ±10%. These design weaknesses converge when small changes occur consistently over time. For example, the amount of area in the SCB with benthos in Reference condition has monotonically decreased between 1994 and 2003 with concomitant increases in the percentage of area at Level 1, but all of these changes were less than five percent. These are potential trends that managers would want to know about, but cannot presently be identified with certainty. Given the limits of trend assessment with the current random design, improved designs to detect trends might be a consideration for future surveys.

VIII. CONCLUSIONS

- **Based on our assessment tools, benthic communities in nearly the entire Southern California Bight are healthy.**

  Benthic macrofauna in 99.7% of the Southern California Bight were in reference condition or deviated only marginally from reference condition in the summer of 2008.

  We could not assess the impacts to the health of benthic communities in several habitats because assessment tools are lacking. These habitats included deep marine ecosystems such as the continental slope and basins (200-1000m deep), the shallow continental shelf (<10 m deep), and estuarine areas with substantial amounts of brackish water (bottom salinity <27 psu). To date, no biointegrity measures have been calibrated and validated for these habitats.

- **Where benthic community impacts were observed, they occurred in embayments such as estuaries and marinas.**

  There was no evidence of benthic community disturbance in the four mainland and island shelf habitats (10-200m depth) in the summer of 2008. However, 12.1% of the embayment area was considered impacted. The most altered benthic communities (High Disturbance or Response Level 3) were only observed in estuaries and marinas. Benthic communities in poor condition occupied 59% of the area in estuaries, 37.4% of the area in marinas, 9.8% of the area in ports, and only 0.1% of other bays.

- **Regional benthic community condition has not changed significantly between 1994 and 2008.**

  No substantial differences were observed in the areal extent of disturbed benthos in habitats that were sampled in more than one regional survey. The areal extent of disturbed benthic community has remained less than 4% of the SCB over the last 15 years. Similarly, there was no consistent pattern of change at sites that were sampled in more than one regional monitoring survey.

- **Special studies to improve cost efficiency in sampling and laboratory analysis from embayment strata did not produce definitive answers.**

  Standard methods for sampling shallow water embayments were adapted from offshore techniques making embayment sites the most laborious and expensive of any benthic infaunal sample collected in Bight' 08. Reducing sample surface area in a gradient from the standard of 0.1 m^2 to a minimum of 0.01 m^2 resulted in a five-fold reduction in laboratory cost. However, the smaller sample area also reduced the number of taxa identified at a site. As a result, the estimated extent of disturbed benthic infaunal communities increased from 12% of embayment area for 0.1 m^2 samples to over 50% of the area for 0.01 m^2 samples.

IX. RECOMMENDATIONS

This chapter presents recommendations for consideration during planning for subsequent regional monitoring surveys in an effort to improve on the success of Bight'08. The recommendations are:

- **Calibrate and validate assessment tools for habitats of concern**.

  The Bight program has done an excellent job at developing benthic macrofaunal community assessment tools for habitats of concern. However, no such assessment tools are available for low salinity estuaries and deep water habitats, although pollutant exposure exists. The development of assessment tools to identify benthic impairments for these two habitats is important and will add value to future regional monitoring activities.

- **Estuaries should continue to be sampled to assess impairment and develop better assessment tools.**

  Approximately half of all saline (>27 psu) estuaries assessed in Bight'08 and Bight'03 exhibited impacted benthic communities, and continued sampling is necessary to track their recovery. However, no assessment tool is available for brackish and freshwater areas (bottom salinity <27 psu) of euryhaline estuaries. Data from previous Bight studies and studies conducted for the State's Sediment Quality Objectives program are available for creating new measures of biotic integrity.

- **Slopes and basins should also continue to be sampled to evaluate the extent of contamination transfer from the shelf to deep water habitats.**

  Sediment chemistry studies for Bight'03 (Schiff *et al.* 2006) and Bight'08 (Schiff *et al.* 2011) showed that deep water habitats had higher sediment contaminant concentrations and an increased propensity to exceed assessment thresholds than sediments on the mainland shelf, where most discharges and related monitoring occurs. However, biointegrity measures are not available for the continental slope and deep basins. Developing assessment measures to detect the presence or absence of altered benthic macrofaunal communities in these areas will help define the areal extent of impacts from human activities in the SCB.

- **Improve cost-effectiveness of sampling embayments and subsequent taxonomic identifications.**

  In Bight'08, embayment samples were subsampled to study the effect of sample surface area on benthic community condition assessments. Unfortunately, this study did not identify an optimal sampling alternative to the existing standard of 0.1 m^2, but cost-effective methods for collecting representative samples in embayment areas are essential for the success of future embayment monitoring and assessments. Three options could be used to identify other cost-efficient alternatives: 1) use a subset of existing assessment tools and thresholds that are insensitive to reductions in sample surface area; 2) develop new thresholds for existing assessment tools that are sensitive to changes in sample surface area; and 3) develop new assessment tools that should be insensitive to sample surface area.

- **Continue revisiting sites to track temporal trends in benthic condition.**

  To facilitate detection of temporal trends, 129 station locations sampled in previous regional monitoring surveys were sampled again during Bight'08. These revisits substantially improved the ability to detect temporal trends by reducing spatial variability. Revisits and any other available techniques should be used to enhance the sensitivity of temporal trend detection.

- **Maintain taxonomic continuity to assure accuracy and reliability**.

  Assessments of biointegrity and biological impacts depend on accurate identifications of organisms collected in samples. Three areas where improvements could result in long-term efficiencies were identified:

  > **Create a taxonomic name change database.** Benthic condition assessments in the Southern California Bight are challenging because taxonomy and benthic invertebrate nomenclature is a constant state of flux, but the species tolerance scores and occurrence probabilities used for condition assessments are associated with names in use at fixed points in time. The BRI used for condition assessments of the mainland shelf is associated with 520 taxon names used in 2001, while the BRI and RIVPACs used for embayment assessments are associated with 264 and 457 taxon names used in 2003, respectively. Associating the sets of names was a challenge that resulted in delays of completion of the Bight'08 assessment. Creation of a database automating association of names in current use with names in use when indices were developed is necessary to facilitate the accuracy of assessments and reduce the time necessary to complete them.
  >
  > **Preserve taxonomic expertise.** A survey conducted by the Southern California Association of Marine Invertebrate Taxonomists (SCAMIT) clearly showed that we are in a crisis of losing the majority of our trained macroinvertebrate taxonomists within the next ten years. In addition, few taxonomists are being trained to replace them. Bight'08 strained the capacity of existing taxonomic laboratories. Managers must start acting now, in collaboration with University partners, to engage taxonomic expertise and enlist students if we are to maintain taxonomic continuity and assure ongoing accuracy and reliability of benthic macroinvertebrate monitoring.
  >
  > **Specialty Taxonomy.** Besides maintaining existing expertise, there are new areas of taxonomic diversity that could be explored. In particular, a large proportion of the taxonomic diversity in estuaries was in the oligochaetes, which are rarely encountered offshore. Specialty taxonomy to evaluate whether there are meaningful delineations within this taxon should be explored prior to the next Bight regional monitoring program.

- **Improve our understanding of the mechanism(s) of impact in estuaries.**

  In Bight'08, estuaries had a disproportionately large frequency and extent of impacted benthic communities. However, the degree of impact due to anthropogenic sources relative to natural perturbations is unknown. For example, sediment contaminants certainly accumulate in estuaries (Schiff *et al.* 2006, Schiff *et al.* 2011). However, these ecosystems are also subject to periodic inundation by fresh water and scour during storm events and perhaps even chronic stress due to marginally increased salinities during dry weather. An improved understanding of the mechanisms and processes that impact estuarine benthos would be an appropriate next step in understanding the extent of biological impacts and the nature of the causes of impact. This understanding does not necessarily have to be a part of a Bight regional monitoring program, but may be undertaken as special studies. Multiple line of evidence assessments integrating benthic communities, sediment chemistry, and toxicity into seasonal studies may be needed to identify causes of impact in estuaries.

- **Implement procedural recommendations**.

  Procedural recommendations for maintaining data quality, improving record keeping, and reducing the time required to produce final data are listed at the end of Chapter 3. Changes due to lessons learned in previous surveys and improvements in automated data submission and reporting have reduced the number of recommendations approximately by half. Implementing these recommendations in future regional monitoring efforts will facilitate the attainment of project objectives in a timely and cost-efficient fashion.

X. LITERATURE CITED

Ackerman, D. and K.C. Schiff. 2003. Modeling stormwater mass emissions to the southern California Bight. *Journal of the American Society of Civil Engineers* 129:308-323.

Alden, R.W., III, S.B. Weisberg, J.A. Ranasinghe and D.M. Dauer. 1997. Optimizing temporal sampling strategies for benthic environmental monitoring programs. *Marine Pollution Bulletin* 34:913-922.

Allan Hancock Foundation. 1959. Oceanographic survey of the continental shelf area of southern California. 20. California State Water Pollution Control Board.

Allan Hancock Foundation. 1965. An oceanographic and biological survey of the southern California mainland shelf. 27. California State Water Pollution Control Board.

Allen, M.J., T.K. Mikel, D.B. Cadien, J.E. Kalman, E.T. Jarvis, K.C. Schiff, D.W. Diehl, S.L. Moore, S.M. Walther, G.B. Deets, C.L. Cash, S.D. Watts, D.J. Pondella, II, V. Raco-Rands, C. Thomas, R. Gartman, L. Sabin, W. Power, A.K. Groce and J.L. Armstrong. 2007. Southern California Bight 2003 Regional Monitoring Program: IV Demersal Fishes and Megabenthic Invertebtrates. Southern California Coastal Water Research Project. Costa Mesa, California, USA.

Anderson, B.S., J.W. Hunt, B.M. Phillips, J. Newman, R.S. Tjeerdema, C.J. Wilson, G. Kapahi, R.A. Sapudar, M. Stephenson, H.M. Puckett, R. Fairey, J.M. Oakden, M. Lyons and S. Birosik. 1998. Sediment chemistry, toxicity, and benthic community conditions in selected water bodies of the Los Angeles region. California State Water Resources Control Board. Sacramento, CA.

Anderson, B.S., J.W. Hunt, B.M. Phillips and R. Fairey. 2001. Sediment quality in Los Angeles Harbor, USA: a triad assessment. *Environmental Toxicology and Chemistry* 20:359-370.

Aquatic Bioassay and Consulting Laboratories. 2004. The marine environment of Marina Del Rey Harbor 2003-2004. Los Angeles County, Department of Beaches and Harbors. Ventura, CA.

Barnard, J.L. and O. Hartman. 1959. The sea bottom off Santa Barbara, California: Biomass and community structure. *Pacific Naturalist* 1:1-16.

Barnard, J.L. and F.C. Ziesenhenne. 1960. Ophiuroid communities of southern California coastal bottoms. *Pacific Naturalist* 2:131-152.

Barnett, A.M., L.G. Gleye, K.D. Green, T.D. Johnson, W. Watson and S.D. Watts. 1987. MEC biological project San Onofre Nuclear Generating Station monitoring studies on mysids and soft bottom benthos Final Report. MEC Analytical Systems, Inc. Encinitas, CA.

Bay, S.M. and K.C. Schiff. 1997. Impacts of stormwater discharges on the nearshore environment of Santa Monica Bay. pp. 105-118 *in*: S.B. Weisberg, C. Francisco and D. Hallock (eds.), Southern California Coastal Water Research Project Annual Report 1996. Southern California Coastal Water Research Project. Westminster, California.

Bay, S.M., T.K. Mikel, K.C. Schiff, S. Mathison, B. Hester, D. Young and D.J. Greenstein. 2005. Southern California Bight 2003 Regional Monitoring Program Volume I: Sediment Toxicity. Southern California Coastal Water Research Project Authority. Westminster, CA.

Bay, S.M. and S.B. Weisberg. 2008. A framework for interpreting sediment quality triad data. pp. 175-185 *in*: S.B. Weisberg and K. Miller (eds.), Southern California Coastal Water Research Project 2008 Annual Report. Southern California Coastal Water Research Project. Costa Mesa, CA.

Bay, S.M., D.J. Greenstein, M. Jacobe, C. Barton, K. Sakamoto, D. Young, K.J. Ritter and K.C. Schiff. 2011. Southern California Bight 2008 Regional Monitoring Program: I. Sediment Toxicity. Southern California Coastal Water Research Project. Costa Mesa, California, USA.

Bay, S.M. and S.B. Weisberg. In Press. Framework for interpreting sediment quality triad data. *Integrated Environmental Assessment and Management*.

Bergen, M. 1996. The Southern California Bight Pilot Project: Sampling Design. pp. 109-113 *in*: M.J. Allen, C. Francisco and D. Hallock (eds.), Southern California Coastal Water Research Project: Annual Report 1994-95. Southern California Coastal Water Research Project. Westminster, California.

Bergen, M., S.B. Weisberg, D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull and R.G. Velarde. 1998. Southern California Bight 1994 Pilot Project Volume IV: Benthic Infauna. Southern California Coastal Water Research Project. Westminster, CA.

Bergen, M., D.B. Cadien, A. Dalkey, D.E. Montagne, R.W. Smith, J.K. Stull, R.G. Velarde and S.B. Weisberg. 2000. Assessment of benthic infaunal condition on the mainland shelf of Southern California. *Environmental Monitoring and Assessment* 64:421-434.

Bergen, M., S.B. Weisberg, R.W. Smith, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull, R.G. Velarde and J.A. Ranasinghe. 2001. Relationship between depth, sediment, latitude, and the structure of benthic infaunal assemblages on the mainland shelf of southern California. *Marine Biology* 138:637-647.

Bight'08 Benthic Committee. 2008. Southern California Bight 2008 Regional Marine Monitoring Survey (Bight'08) Macrobenthic (Infaunal) Sample Analysis Laboratory Manual. Southern California Coastal Water Research Project Authority. Costa Mesa, California, USA.

Bight'08 Coastal Ecology Committee. 2008. Southern California Bight 2008 Regional Marine Monitoring Survey (Bight'08) Coastal Ecology Workplan. Southern California Coastal Water Research Program Authority. Costa Mesa, California.

Bight'08 Field Sampling & Logistics Committee. 2008. Southern California Bight 2008 Regional Marine Monitoring Survey (Bight'08) Field Operations Manual. Southern California Coastal Water Research Project. Costa Mesa, California, USA.

Bight'08 Information Management Committee. 2008. Southern California Bight 2008 Regional Marine Monitoring Survey (Bight'08) Information Management Plan. Southern California Coastal Water Research Project. Costa Mesa, California, USA.

Borja, Á., J. Franco and V. Perez. 2000. A marine biotic index to establish the ecological quality of soft-bottom benthos within european estuarine and coastal environments. *Marine Pollution Bulletin* 40:1100-1114.

Borja, Á., I. Muxika and J. Franco. 2003. The application of a marine biotic index to different impact sources affecting soft-bottom benthic communities along european coasts. *Marine Pollution Bulletin* 46:835-845.

Cimberg, R.L., R.W. Smith and D.B. Cadien. 1993. Distribution of benthic infaunal communities in the vicinity of Point Conception, California. Third California Islands Symposium - Recent Advances in Research on the California Islands. Santa Barbara, California, USA.

City of Los Angeles Environmental Monitoring Division. 2003. Santa Monica Bay Bienniel Assessment Report 2001-2002. City of Los Angeles, Dept. of Public Works, Bureau of Sanitation. Los Angeles, California, USA.

City of San Diego. 2006. Annual Receiving Waters Monitoring Report for the Point Loma Ocean Outfall, 2005. Chapter 5: Macrobenthic Communities. . City of San Diego Ocean Monitoring Program, Metropolitan Wastewater Department, Environmental Monitoring and Technical Services Division. San Diego, CA.

Connor, E.F. and E.D. McCoy. 1979. The statistics and biology of the species-area relationship. *American Naturalist* 113:791-833.

Dauer, D.M. 1997. Dynamics of an estuarine ecosystem: Long-term trends in the macrobenthic communities of Chesapeake bay, (1985-1993). *Oceanologica Acta* 20:291-298.

Diener, D.R., S.C. Fuller, A.L. Lissner, C.I. Haydock, D. Maurer, G. Robertson and T. Gerlinger. 1995. Spatial and temporal patterns of the infaunal community near a major ocean outfall in Southern California. *Marine Pollution Bulletin* 30:861-878.

Dorsey, J.H., C.A. Phillips, A. Dalkey, J.D. Roney and G.B. Deets. 1995. Changes in assemblages of infaunal organisms around wastewater outfalls in Santa Monica Bay, California. *Bulletin of the Southern California Academy of Sciences* 94:46-64.

Engle, V.D., J.K. Summers and G.R. Gaston. 1994. A benthic index of environmental condition of Gulf of Mexico estuaries. *Estuaries* 17:372-384.

Engle, V.D. and J.K. Summers. 1999. Refinement, validation, and application of a benthic condition index for Northern Gulf of Mexico estuaries. *Estuaries* 22:624-635.

Fairey, R., C. Bretz, S. Lamerdin, J.W. Hunt, B.S. Anderson, S. Tudor, C.J. Wilson, F. LaCaro, M. Stephenson, H.M. Puckett and E.R. Long. 1996. Chemistry, toxicity and benthic community conditions in sediments of the San Diego Bay region. California State Water Resources Control Board. Sacramento, CA.

Fauchald, K. and G.F. Jones. 1978. Variation in Community Structure of Shelf, Slope and Basin Macrofaunal Communities of the Southern California Bight. SAI-77-917-LJ. University of Southern California.

Ferraro, S.P. and F.A. Cole. 2004. Optimal benthic macrofaunal sampling protocol for detecting differences among four habitats in Willapa Bay, Washington, USA. *Estuaries* 27:1014-1025.

Ferraro, S.P., F.A. Cole and A.R. Olsen. 2006. A more cost-effective EMAP benthic macrofaunal sampling protocol. *Environmental Monitoring and Assessment* 116:275-290.

Hammerstrom, K.K., J.A. Ranasinghe, S.B. Weisberg, J.S. Oliver, W.R. Fairey, P.N. Slattery and J.M. Oakden. In Press. Effect of sample area and sieve size on benthic macrofaunal community condition assessments in California enclosed bays and estuaries. *Integrated Environmental Assessment and Management*.

Hartman, O. 1955. Quantitative survey of the benthos of San Pedro Basin, Southern California. Part I, Preliminary Results. pp. 1-185., Allan Hancock Pacific Expeditions 19, No. 1.

Hartman, O. and J.L. Barnard. 1958. The benthic fauna of the deep basins off Southern California. pp. 1-67, Allan Hancock Pacific Expeditions 22, No. 1.

Hartman, O. and J.L. Barnard. 1960. The benthic fauna of the deep basins off Southern California. Part II. pp. 1-19, Allan Hancock Pacific Expeditions 22, No. 2.

Hartman, O. 1963. Submarine canyons of Southern California, Part II - Biology. pp. 1-424., Allan Hancock Pacific Expeditions 27, No. 2.

Hartman, O. 1966. Quantitative survey of the benthos of San Pedro Basin, Southern California. Part II. Final results and conclusions. pp. 187-456, Allan Hancock Pacific Expeditions 19, No. 2.

Hunt, J.W., B.S. Anderson, B.M. Phillips, R.S. Tjeerdema, K.M. Taberski, C.J. Wilson, H.M. Puckett, M. Stephenson, R. Fairey and J.M. Oakden. 2001. A large-scale categorization of sites in San Francisco Bay, USA, based on the sediment quality triad, toxicity identification evaluations, and gradient studies. *Environmental Toxicology and Chemistry* 20:1252-1265.

James, R.J., M.P.L. Smith and P.G. Fairweather. 1995. Sieve mesh-size and taxonomic resolution needed to describe natural spatial variation of marine macrofauna. *Marine Ecology Progress Series* 118:187-198.

Jones, G.F. 1969. The benthic macrofauna of the mainland shelf of southern California. *Allan Hancock Monographs in Marine Biology* 4:1-219.

Levin, L.A., R.J. Etter, M.A. Rex, A.J. Gooday, C.R. Smith, J. Pineda, C.T. Stuart, R.R. Hessler and D.L. Pawson. 2001. Environmental influences on regional deep-sea species diversity. *Annual Review of Ecology and Systematics* 32:51-93.

Llansó, R.J., L.C. Scott, J.L. Hyland, D.M. Dauer, D.E. Russell and F.W. Kutz. 2002. An estuarine benthic index of biotic integrity for the Mid-Atlantic region of the United States. II. Index Development. *Estuaries* 25:1231-1242.

Los Angeles County Sanitation Districts. 2006. Palos Verdes Ocean Monitoring Annual Report, 2005. Chapter 3: Sediments and Infauna. Los Angeles County Sanitation Districts. Whittier, CA.

MEC Analytical Systems Inc and Weston Solutions Inc. 2005. San Diego County Municipal Co-permittees 2003-2004 Urban Runoff Monitoring. County of San Diego. San Diego, CA.

Muxika, I., Á. Borja and W. Bonne. 2005. The suitability of the marine biotic index (AMBI) to new impact sources along european coasts. *Ecological Indicators* 5:19-31.

Muxika, I., Á. Borja and J. Bald. 2007. Using historical data, expert judgment and multivariate analysis in assessing reference conditions and benthic ecological status, according to the european Water Framework Directive. *Marine Pollution Bulletin* 55:16-29.

Orange County Sanitation District. 2006. Annual Report 2005. Marine Monitoring. Chapter 5 - Marine Infaunal Communities. Orange County Sanitation District. Fountain Valley, CA.

Paul, J.F., K.J. Scott, D.E. Campbell, J.H. Gentile, C.S. Strobel, R.M. Valente, S.B. Weisberg, A.F. Holland and J.A. Ranasinghe. 2001. Developing and applying a benthic index of estuarine condition for the Virginian Biogeographic Province. *Ecological Indicators* 1:83-99.

Pearson, T.H. and R. Rosenberg. 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanography and Marine Biology: An Annual Review* 16:229-311.

Pielou, E.C. 1969. An introduction to mathematical ecology. Wiley-Interscience. New York, NY.

Preston, F.W. 1948. The commonness, and rarity, of species. Ecology 29:254-283. *Ecology* 29:254-283.

Ranasinghe, J.A., D.E. Montagne, R.W. Smith, T.K. Mikel, S.B. Weisberg, D.B. Cadien, R.G. Velarde and A. Dalkey. 2003a. Southern California Bight 1998 Regional Monitoring Program: VII. Benthic Macrofauna. Technical Report 382. Southern California Coastal Water Research Project. Westminster (CA), USA.

Ranasinghe, J.A., D.E. Montagne, S.B. Weisberg, M. Bergen and R.G. Velarde. 2003b. Variability in the identification and enumeration of marine benthic invertebrate samples and its effect on benthic assessment measures. *Environmental Monitoring and Assessment* 81:199-206.

Ranasinghe, J.A., A.M. Barnett, K.C. Schiff, D.E. Montagne, C.A. Brantley, C. Beegan, D.B. Cadien, C.L. Cash, G.B. Deets, D.R. Diener, T.K. Mikel, R.W. Smith, R.G. Velarde, S.D. Watts and S.B. Weisberg. 2007. Southern California Bight 2003 Regional Monitoring Program: III Benthic Macrofauna. Technical Report 529. Southern California Coastal Water Research Project. Costa Mesa (CA), USA.

Ranasinghe, J.A., S.B. Weisberg, R.W. Smith, D.E. Montagne, B. Thompson, J.M. Oakden, D.D. Huff, D.B. Cadien, R.G. Velarde and K.J. Ritter. 2009. Calibration and evaluation of five indicators of benthic community condition in two California bay and estuary habitats. *Marine Pollution Bulletin* 59:5-13.

Ranasinghe, J.A., K.C. Schiff, D.E. Montagne, T.K. Mikel, D.B. Cadien, R.G. Velarde and C.A. Brantley. 2010. Benthic macrofaunal community condition in the Southern California Bight, 1994–2003. *Marine Pollution Bulletin* 60:827-833.

Rey, J.R., D.R. Strong and E.D. McCoy. 1982. On overinterpretation of the species-area relationship. *American Naturalist* 119:741-743.

Rosenberg, R., M. Blomqvist, H.C. Nilsson, H. Cederwall and A. Dimming. 2004. Marine quality assessment by use of benthic species-abundance distributions: a proposed new protocol within the European Union Water Framework Directive. *Marine Pollution Bulletin* 49:728-739.

Sanitation Districts of Los Angeles County. 2010. Joint Water Pollution Control Plant: Bienniel Receiving Water Monitoring Report 2008-2009. County Sanitation Districts of Los angeles County. Whittier, California, USA.

Scheltema, A.H. 1997. Aplacophoran molluscs: deep-sea analogs to polychaetes. *Bulletin of Marine Science* 60:575-583.

Schiff, K.C., S.M. Bay and D.W. Diehl. 2003. Stormwater toxicity in Chollas Creek and San Diego Bay. *Environmental Monitoring and Assessment* 81:119-132.

Schiff, K.C., D.W. Diehl and A. Valkirs. 2004. Copper emissions from antifouling paint on recreational vessels. *Marine Pollution Bulletin* 48:371-377.

Schiff, K.C., K. Maruya and K. Christenson. 2006. Southern California Bight 2003 Regional Monitoring Program Volume II: Sediment Chemistry. Southern California Coastal Water Research Project. Westminster (CA), USA.

Schiff, K.C., R.W. Gossett, K.J. Ritter, L.L. Tiefenthaler, N. Dodder and K. Maruya. 2011. Southern California Bight 2008 Regional Monitoring Program: III. Sediment Chemistry. Southern California Coastal Water Research Project. Costa Mesa, California, USA.

Setty, K.E., K.C. Schiff, J.R. Gully and S.B. Weisberg. 2010. Evolution of monitoring program design for marine outfalls in the Southern California Bight. . pp. 1-13 *in*: S.B. Weisberg and K. Miller (eds.), Southern California Coastal Water Research Project 2010 Annual Report. Southern California Coastal Water Research Project. Costa Mesa, CA.

Smith, R.W., M. Bergen, S.B. Weisberg, D.B. Cadien, A. Dalkey, D.E. Montagne, J.K. Stull and R.G. Velarde. 2001. Benthic response index for assessing infaunal communities on the southern California mainland shelf. *Ecological Applications* 11:1073-1087.

Smith, R.W., J.A. Ranasinghe, S.B. Weisberg, D.E. Montagne, D.B. Cadien, T.K. Mikel, R.G. Velarde and A. Dalkey. 2003. Extending the southern California Benthic Response Index to assess benthic condition in bays Technical Report 410. Southern California Coastal Water Research Project. Westminster (CA), USA.

Southern California Association of Marine Invertebrate Taxonomists. 2008. A taxonomic listing of macro- and megainvertebrates from infaunal and epibenthic programs in the Southern California Bight. Edition 5. Southern California Association of Marine Invertebrate Taxonomists. Los Angeles, California, USA.

Southern California Edison Company. 1997. Annual marine environmental analysis and interpretation: Report on 1996 data, San Onofre Nuclear Generating Station. Southern California Edison, ECOSystems Management, and Ogden Environmental and Energy Services. San Clemente, CA.

Stevens, D.L., Jr. 1997. Variable density grid-based sampling designs for continuous spatial populations. *Environmetrics* 8:167-195.

Stevens, D.L., Jr. and T.M. Kincaid. 1997. Variance estimation for subpopulation parameters from samples of spatial environmental populations. pp., Proceedings of the American Statistical Association section on statistics and the environment. American Statistical Association. Alexandria, VA.

Stevenson, R.E. 1961. The oceanography of the Southern California mainland shelf. Report to the California State Water Pollution Control Board (Contract 12c-12).

Stull, J.K., C.I. Haydock, R.W. Smith and D.E. Montagne. 1986. Long-term changes in the benthic community on the coastal shelf of Palos Verdes, Southern California. *Marine Biology* 91:539-551.

Swartz, R.C., F.A. Cole, D.W. Schults and W.A. DeBen. 1986. Ecological changes in the Southern California Bight near a large sewage outfall: benthic conditions in 1980 and 1983. *Marine Ecology Progress Series* 31:1-13.

Tapp, J.F., N. Shillabeer and C.M. Ashman. 1993. Continued observation of the benthic fauna of the industrialized Tees estuary, 1979-1990. *Journal of Experimental Marine Biology and Ecology* 172:67-80.

Teixeira, H., Á. Borja, S.B. Weisberg, J.A. Ranasinghe, D.B. Cadien, D.M. Dauer, J.-C. Dauvin, S. Degraer, R.J. Diaz, A. Grémare, I. Karakassis, R.J. Llansó, L.L. Lovell, J.C. Marques, D.E. Montagne, A. Occhipinti-Ambrogim, R. Rosenberg, R. Sardá, L.C. Schaffner and R.G. Velarde. 2010. Assessing coastal benthic macrofauna community condition using best professional judgement – Developing consensus across North America and Europe. *Marine Pollution Bulletin* 60:589-600.

Thompson, B., J.D. Laughlin and D.T. Tsukada. 1987. 1985 reference site survey. Technical Report 221. Southern California Coastal Water Research Project. Long Beach, CA.

Thompson, B., J. Dixon, S. Schroeter and D.J. Reish. 1993a. Chapter 8: Benthic Invertebrates. pp. 369-458 *in*: M.D. Dailey, D.J. Reish and J.W. Anderson (eds.), Ecology of the Southern California Bight. University of California Press. Berkeley and Los Angeles.

Thompson, B., D.T. Tsukada and D. O'Donohue. 1993b. 1990 reference site survey. Technical Report 269. Southern California Coastal Water Research Project. Westminster, California.

Thompson, B. and S. Lowe. 2004. Assessment of macrobenthos response to sediment contamination in the San Francisco Estuary, California, USA. *Environmental Toxicology and Chemistry* 23:2178-2187.

Thompson, B., S.B. Weisberg, A.R. Melwani, S. Lowe, J.A. Ranasinghe, D.B. Cadien, D.M. Dauer, R.J. Diaz, W. Fields, M. Kellogg, D.E. Montagne, P.R. Ode, D.J. Reish and P.N. Slattery. 2012. Low levels of agreement among experts using best professional judgment to assess benthic condition in the San Francisco estuary and delta. *Ecological Indicators* 12:167-173.

Thompson, S.K. 1992. Sampling. J. Wiley and Sons. New York, NY.

U.S. Environmental Protection Agency. 1987. Environmental impact statement for San Diego (LA-5) ocean dredged material disposal site designation. San Francisco, CA.

Van Dolah, R.F., J.L. Hyland, A.F. Holland, J.S. Rosen and T.R. Snoots. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern USA. *Marine Environmental Research* 48:269-283.

Van Sickle, J., D.D. Huff and C.P. Hawkins. 2006. Selecting discriminant function models for predicting the expected richness of aquatic macroinvertebrates. *Freshwater Biology* 51:359-372.

Weisberg, S.B., B. Thompson, J.A. Ranasinghe, D.E. Montagne, D.B. Cadien, D.M. Dauer, D.R. Diener, J.S. Oliver, D.J. Reish, R.G. Velarde and J.Q. Word. 2008. The level of agreement among experts applying best professional judgment to assess the condition of benthic infaunal communities. *Ecological Indicators* 8:389-394.

Weston Solutions Inc. 2005. San Diego County Municipal Co-permittees 2004-2005 Urban Runoff Monitoring. County of San Diego. San Diego, CA.

Wilson, J.G. and D.W. Jeffrey. 1994. Benthic biological pollution indices in estuaries. pp. 311-327 *in*: K.J.M. Kramer (ed.), Biomonitoring of coastal waters and estuaries. CRC Press, Inc. Boca Raton, FL.

Word, J.Q. 1975. A comparative field study of benthic sampling devices used in Southern California marine surveys. Southern California Coastal Water Research Project. Long Beach, California.

Word, J.Q. 1976a. Biological comparison of grab sampling devices. pp. 189-194, Southern California Coastal Water Research Project 1976 Annual Report. Southern California Coastal Water Research Project. El Segundo (CA), USA.

Word, J.Q. 1976b. A comparative field study of benthic sampling devices used in southern California benthic surveys. Technical Report 85, EPA Grant R801152. Southern California Coastal Water Research Project. Long Beach, CA.

Word, J.Q. and A.J. Mearns. 1979. 60-m control survey off Southern California. Technical Memorandum 229. Southern California Coastal Water Research Project. El Segundo, California.

Wright, J.F., M.T. Furse and P.D. Armitage. 1993. RIVPACS: a technique for evaluating the biological water quality of rivers in the UK. *European Water Pollution Control* 3:15-25.

Zmarzly, D.L., T.D. Stebbins, D. Pasko, R.M. Duggan and K.L. Barwick. 1994. Spatial patterns and temporal succession in soft-bottom macroinvertebrate assemblages surrounding an ocean outfall on the southern San Diego shelf: relation to anthropogenic and natural events. *Marine Biology* 118:293-307.

APPENDIX A: PARTICIPANTS IN THE BIGHT'08 REGIONAL MONITORING PROGRAM

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_A.pdf

APPENDIX B: COMMUNITY MEASURES FOR SAMPLING STRATA

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_B.pdf

APPENDIX C: TAXONOMIC COMPOSITION FOR SAMPLING STRATA

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_C.pdf

APPENDIX D: MAPS OF BENTHIC CONDITION AT SAMPLING SITES

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_D.pdf

APPENDIX E: COMMUNITY MEASURES AT OFFSHORE SITES

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_E.pdf

APPENDIX F: COMMUNITY MEASURES AT EMBAYMENT SITES

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_F.pdf

APPENDIX G: ENCOUNTERED SPECIES LIST

ftp://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/665_B08Benthic_Appendix_G.pdf